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# ICE FLOW AND BLOCKAGE INVESTIGATION OF SHROUDED PROPELLERS

by

VLODEK LASKOW
of
**ARCTIC RESEARCH AND DEVELOPMENT LIMITED**
Bragg Creek, Alberta

in cooperation with

**NORDCO LIMITED**
St. John's, Newfoundland

and

**INSTITUTE FOR MARINE DYNAMICS**
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16. Abstract

This report describes a series of model tests and analytical investigation of ice flow and blockage of shrouded propellers. The tests were done using a 1:15 scale model of the Louis S. St. Laurent equipped with a centreline nozzle. The tests performed were:

- ☆ Ice block buoyancy tests
- ☆ Friction tests
- ☆ Waterjet tests
- ☆ Overload tests with and without an ice deflector
- ☆ Simulated blockage tests
- ☆ Wing shaft interference tests
- ☆ Broken ice flow tests, with and without the deflector

The influence of ship speed, draft, power and other parameters on ice/propeller interaction frequency and blockage frequency is established. Blockage forces are determined as a function of blocking piece geometry, power developed and direction of motion. The effectiveness of waterjets and ice deflectors is discussed. Various means of minimizing blockage severity are discussed in the conclusions and recommendations.

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16. Résumé

Ce rapport décrit la série d'essais sur maquette et les travaux de recherche analytique sur le comportement des hélices protégées par une tuyère, notamment sous l'angle de l'écoulement des fragments de glaces et des phénomènes de blocage. Pour cela, une maquette 1:15 du Louis Saint-Laurent équipée d'une tuyère protégeant l'hélice centrale a été utilisée. Les essais suivants ont été menés:

- Emergence des fragments de glace
- Frottement
- Jets d'eau
- Essais de surcharge avec et sans déflecteur
- Simulation d'un blocage
- Interférence des hélices d'extrémité
- Ecoulement des fragments de glace, avec et sans déflecteur

L'influence de la vitesse de marche, du tirant d'eau, de la puissance et d'autres paramètres sur la fréquence des impacts hélices-glaces, et celle des blocages du tuyère, a été déterminée. De même que les forces exercées lors d'un blocage, qui sont fonction de la géométrie des fragments, de la puissance motrice et du sens de la marche. Le rapport traite également de l'efficacité des jets d'eau et autres dispositifs de déflexion et, au chapitre des conclusions et des recommandations, des moyens permettant de réduire au minimum les conséquences d'un blocage de la tuyère.

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*Mr.* ***Pierre Semery*** *(TDC), and*

*Mr.* ***Jacques Asselin*** *(CCG)*

EXECUTIVE SUMMARY

## 1. Introduction

Nozzles offer two significant advantages for ice going ships:

**increased thrust** for the same power delivered, and

**protection** of the propellers.

The disadvantages of such installations are their clogging with ice and blockage of the entrance with ice blocks.

In order **to understand** the blockage phenomena and to **develop the countermeasures** this project was initiated.

The requirement of this project was to investigate the ice flow and blockage phenomena **using the existing 1:15 scale model of CCG Louis S. St. Laurent**, equipped with a **centerline nozzle.**
The test plan, equipment and instrumentation evolved around this requirement.

## 2. Project objectives

The objectives of this project are:

- Evaluation of the flow pattern of ice pieces under the hull and into the nozzle mouth,
- Investigation of the influence of the blocking on the power, torque and thrust capability of the shrouded propeller,
- Evaluation of the variation of the performance of the propeller/nozzle system as a function of the blockage,
- Proposal of a solution to minimize the blockage problem, including the evaluation of the waterjets.

## 3. Work plan

*The existing state of the art on the blockage and related phenomena was reviewed. Based on this, the testing programme was designed to be implemented in two phases:*

*Phase 1*

- *basic tests of ice and the propulsion in open water*
- *tests in ice*
- *waterjet tests*

*Phase 2*

- *basic tests with an anti - blockage device*
- *tests in a simulated ice field with the device*

*The anti-blocking device was designed after a review of the Phase 1 test results.*

*Due to the problems with the attachment of the deflector to the hull, and the propeller damage, Phase 2 was only partially successful.*

## 4. Literature search

*The literature search identified 15 references dealing with the blockage phenomena in the full scale, model scale and analytical domains. All of those identified the blockage phenomenon as having the following characteristics:*

*increased propeller thrust*
*increased propeller torque*
*decrease of the nozzle thrust*
*large vibrations of the system.*

*The largest propeller thrust fluctuations during the blockage were recorded during the full scale trials of MV Robert LeMeur (4.7 times the hydrodynamic thrust). The maximum torque recorded was twice the bollard MCR torque.*

*A number of papers identified the advantages of the nozzle when compared with the unshrouded propellers. For the centerline sha of CCG Louis S.St.Laurent(LSSL), the following numbers have been* developed by the author:

| | |
|---|---|
| Thrust of the system (shrouded/open) at 3kn ahead: | **1.38** |
| Bollard pull astern (shrouded/open): | **1.58** |
| Maximum speed achievable (shrouded/open): | **0.99** |
| Cavitation potential(shrouded open): | **small/large** |
| Maximum thrust/power ratio bollard ahead: | **17 kG/HP** |
| bollard astern | **14 kG/HP** |
| Average thrust/power ratio bollard ahead: | **11.4 KG/HP** |

Nozzles are reported **to block with ice,** in particular on the **shallow draft vessels,** impeding their operations. **No breaking** of the shrouded propeller blade **was ever reported** due to ice.

The maximum impact forces on the nozzle reported due to ice was on a nozzle having similar diameter (Polar Stern) to that of LSSL:

210 tonnes astern
120 tonnes ahead

The design ice impact force on the centerline nozzle of the ship was determined to be:

780 tonnes

The model tests report the following blockage manifestations:

* The mean values of thrust and torque increased 220% to 250% of the mean steady hydrodynamic forces.

* The peak to peak excursions of the

| | | |
|---|---|---|
| longitudinal blade force | **increased** | 1,000% |
| torque | " | 130% |
| thrust | " | 100% |
| blade spindle torque | " | 3,400% |
| The shaft bending moments | " | 700% |

The model testing teams warn against the difficulties in the measurements and control of the blockage experiments due to the high level of vibratory forces occurring during the tests.

A quick drop of the blockage induced forces is reported when the blocking piece is distanced away from the nozzle mouth.

The parameters identified as important in determining ice/propeller interaction frequency were:

bow shape
ship length
ship draft and beam
flatness of the bottom
number and configurations of the shafts,
propeller submergence

*shaft power*
*ship speed and*
*ice conditions*

*The means of preventing and/or alleviating the severity of blockages identified in the literature are:*

- *ice deflecting devices (fins, deflectors, cages),*
- *water bypass devices (slots in the nozzle rings) and*
- *air injection into the propulsor/nozzle.*

## 5. Testing programme

*The existing model was refurbished, reinforced and equipped with the centerline nozzle and propeller. A large quantity of the simulated ice blocks were manufactured from wax. A corral was built to contain the simulated broken ice field. Also the waterjet and the jet force measuring apparatus were manufactured prior to the tests. A new dynamometer, capable of sustaining large forces due to the blockage, was installed on the centerline shaft. The following tests were executed:*

*TABLE EXEC1*

*SUMMARY OF THE TESTS*

| Test name | Purpose |
|---|---|
| Float-up tests | to determine the float-up and hydrodynamic characteristics of ice blocks. |
| Friction tests | to determine the friction factors in the blocks/blocks and blocks/hull interaction. |
| Waterjet tests | to determine the effectiveness of waterjets as an ice clearing and anti-blockage device. |
| Overload tests | to determine the propulsive characteristics of the model equipped with the nozzle in ice free water. |
| Blockage tests | to determine the blockage forces and characteristics. |
| Tests in ice w/o the deflector | to determine the ice flow and ice/propeller/nozzle characteristics in function of ship and ice parameters. |
| Overload tests | to determine the change in the open water |

| | |
|---|---|
| with the deflector | performance of the model equipped with the deflector. |
| Tests in ice<br>with the deflector | to compare the performance of the nozzle/propeller system to that without the deflector. |

*The ice model basin was not available for this project. Therefore an open water basin was used with wax as a broken ice simulating medium.*

*The wax proved to be an excellent testing medium, possessing good buoyancy and frictional characteristics suited for this type of testing. Its strength was too high, however, and not controllable within the means of this project.*

*The model made of the fiberglass reinforced foam proved to be too fragile and too flexible for this particular application. Its flexibility influenced the alignment of the shaftline and the signals collected from it. The strength of the attachment of the appendages was also very limited,resulting in the destruction of the deflector installed in the last test series.*

## 6. RESULTS OF FLOAT-UP TESTS

1. *Emergence time is proportional to the depth.*
2. *Emerging ice blocks attain quickly the limiting speed of ascent which is a constant for the block.*
3. *The critical (limiting) speed* **Vcr** *is dependent on:*

   *ice block thickness* **Hi,**
   *ratio of ice density to water density* **row/roi**
   *drag coefficient* **cr.**
   *gravity constant* **g**

   **Vcr = (2*g*Hi*(row/roi -1)/cr)^0.5**................E.1

4. *Free ice float-up motion is well represented by the analytical formulations given in the text.*
5. *Motions of ice blocks are oscillatory, but stable.*
6. *Heavier ice blocks emerge faster than the light ones. For the sizes tested and depth of 1.6m, we have:*

   *emergence time = 14.8 -1.898 * block weight..............E.2*

*7. Edge-up emergence is faster than the flat face up.*

*8. Distance travelled by an emerging ice block can be approximated by a formula:*

$$z(t) = a + Vcr * t \qquad \text{E.3}$$

*where* ***a*** *is a constant particular to the specifics of an ice block, and* ***Vcr*** *is the limiting velocity.*

*9. Effective added mass coefficient of ice block is approximately 4.*

*10. Effective drag coefficient of ice blocks decreases with an increase of ice block thickness.*

*11. Float-up time of an ice block* ***near the wall*** *is approximately* ***4 times longer*** *than the free float-up time.*

*12. Float-up times of ice blocks released from the bottom of the model* ***decrease with an increase of block's weight.***

*13. For the block tested, average float-up time from the bottom of the model was 2 sec. The longest time was at the midbody position.*

*14. For suddenly accelerated ice blocks, the average speed of travel was* ***inversely proportional to an initial acceleration***

*15.* ***There exists a critical speed*** *beyond which an ice block's free motion becomes unstable and overall speed slows down.*

*16. In order to attain large distances when pushing ice blocks away,* ***gentle accelerations below the critical speed*** *are needed, not sudden large magnitude impulses.*

## *7. RESULTS OF FRICTION TESTS*

- *Wax blocks used in this project have frictional properties very* ***compatible with the full scale, low pressure measurements*** *of friction ice/ INERTA 160.*

- *Method of measurements used, which reflects the actual physics of interaction between the submerged ice blocks and the hull,* ***is convenient and gives consistent results.***

- *Friction factor of wax/hull surface is* ***0.24,*** *and varies slightly with the surface finish and condition.*

- *Friction factor wax/hull is* ***not dependent on the weight*** *of the ice blocks except for a slight decrease of the friction factor observed only for a wet wax on wax condition, which simulates the friction between the blocks.*

- Water presence **increases the friction factor from 0.21 to 0.28** for wax/wax condition.

- Friction between wax and hull is smaller than the friction between the blocks (**0.24 versus 0.28**).

## 8. RESULTS OF WATERJET TESTS

### General

1. Test method was successful and yielded useful information about the thrust of submerged jets.

   Maximum thrust measured was **26.4 N**
   Maximum power developed by the jet was **440 Watts.**

2. Froude's Scaling Laws can be applied to extrapolate the model tests results to the full scale applications.

   Thrust of the jet scales up with $(la)^3$

   Power of the jet scales up with $(la)^{3.5}$

### Analytical computations

1. Calculations of the jet force by means of adding of static and dynamic components gives good results.

2. Calculations of the force using the jet force formula is a good approximation in the whole range tested.

$$F = 1025 * V^2 * \text{orifice area} \ldots\ldots\ldots\ldots \text{E.4}$$

   (all dimensions in SI units)

3. Force on the target can be computed in a first approximation by using the power of the jet as follows:

$$F = C * (4 * (\text{Jet power})^2 * ro * \text{Orif area})^{1/3} \ldots\ldots \text{E6.5}$$

   where C is the distance coefficient computed from:

$$C = 1.03 - 0.3343 * \text{distance} \ldots\ldots\ldots\ldots \text{E.6}$$

   Above formula is valid only for the range of powers tested.

### Maximum force/distance

The force on the target **drops proportionately** with the distance from the target.

*The drop is **small for medium and large size nozzles** and large for small size nozzle. Drop is linear, for the range tested.*

**Maximum force/nozzle area**

*Increasing the nozzle area increases the force until a cut off is achieved due to the limitations of the system supply.*

**Maximum force/ pressure**

*The maximum force on the target increases nearly proportionately with the pressure in the system.*

**Maximum force/ medium**

*The maximum force in water is larger than the maximum force in air.*

**Efficacy of the system**

*Nozzles used in these tests were of simple design, hydraulically comparable to the sharp edge opening in a wall of a tank.*

*The average (for all the tests) thrust/power efficacy coefficient of the jet increases linearly with the increase of nozzle aperture area.*

*For the nozzle tested, average efficacy was **6.15 kG/HP** for the medium nozzle.*

## 9. RESULTS OF OVERLOAD TESTS

1. *The centerline nozzle and propeller develop **11.4 kG/HP** (full scale) which is **more than 35% higher** than the corresponding open propeller, in bollard condition.*
2. *Thrust astern in the bollard astern condition is approximately equal to the thrust ahead of the system, in ahead bollard condition, for the same RPS.*
3. *High astern thrust of the system (**70% of the bollard ahead**) is maintained even at **6 knots astern** speed.*
4. *The above **findings confirm fully the results** of the investigations contained in the Reference 1.*
5. ***Nozzle develops more thrust than the propeller** at bollard ahead condition.*
6. *The location of the nozzle thrust vector changes with the change of nozzle load, especially the vertical one.*

7. *The location of the thrust vector is predominantly below the nozzle axis.*

8. *Centerline nozzle/propeller system delivers* ***more than 1/3*** *of the total three shafts thrust, for the constant RPS, for all conditions tested (from 40% to 60% of the total).*

9. *The thrust deduction factor is* ***0.23*** *for the centerline nozzle and propeller system, in the ahead bollard condition and with the wing propellers stopped.*

10. *For the astern bollard condition, the thrust deduction factor is* ***0.32.***

## *10. RESULTS OF THRUST CHANGE AS A RESULT OF WING PROPELLER INTERFERENCE*

1. *There is sufficient data to conclude that the wing propellers* ***cause considerable disturbance*** *in the working of the centerline propeller and nozzle.*

2. *For the full power ahead, a* ***considerable gain*** *in the nozzle can be anticipated, by an analogy with the axial pumps working in series. For the astern condition,* ***severe penalty*** *in the centerline thrust may take place.*

## *11. RESULTS OF BLOCKAGE TESTS*

*BLOCKAGE CHARACTERISTICS*

1. *Blockage leads to the following (for the constant RPS):*

   *increase of the shaft thrust,*
   *increase of the shaft torque,*
   *decrease of the nozzle thrust,*
   *decrease of the total thrust,*
   *increase of the power absorbed,*
   *decrease of the tow rope pull,*
   *increased level of vibration of the nozzle, propeller and shaftline.*

2. *Nozzle blockage corresponds hydrodynamically to the condition when the vessel is moving at a certain speed in open water but the propeller works in* ***a strong wake,*** *that is at* ***much lower speed of advance than the ship (even negative speed of advance),*** *and the propeller rotates in the forward direction.*

PERFORMANCE OF PROPELLER/NOZZLE IN BLOCKED CONDITION

3. *The largest* ***nozzle thrust drop*** *was recorded from the* ***+65%*** *in the non-blocked condition to* ***-50%*** *of the total system thrust at the bollard when the middle part of the nozzle was blocked and all three shafts were working. A slight increase of the nozzle thrust was noted when the device was placed some 10cm in front of the nozzle mouth.*

4. *The performance indicators, like tow pull/power developed or the total system thrust/power developed dropped with introduction of blockage from approximately* ***100% to 25%*** *in the* ***middle blocked condition.***

5. ***The most severe blockage condition,*** *in terms of the tow pull/power delivered, occurred when the* ***middle part o****f the nozzle was blocked. The least severe was when the device was placed 10 cm ahead of the nozzle. In terms of the tow pull/power delivered, the following is the order of performance:*

TABLE EXEC2

Summary of system performance

| PERFORMANCE | CONDITION<br>BOLLARD AHEAD | BOLLARD ASTERN | AREA BLOCKED |
|---|---|---|---|
| best | no blockage | no blockage | 0% |
| | 10 cm distance | | |
| | top blocked | top blocked | 20% |
| | bottom blocked | bottom blocked | 23% |
| | 5 cm distance | | |
| worst | middle blocked | middle blocked | 47% |

6. ***Wing shafts increase blockage severity,*** *by providing an additional drag force on the blocking piece, which translates into the lower overall nozzle thrust.*

7. *Vessel speed decreases the total thrust/power delivered ratio substantially in the blocked condition.*

8. ***In the astern condition the effects of the blockage were more moderate*** *than in the ahead condition.*

SUCTION FORCES

8. *Suction forces on the block placed ahead of the nozzle mouth* ***depend strongly on the propeller thrust.***

9. *The suction forces decrease with the increase of speed.*

10. The suction forces at a piece placed 5 cm ahead of the nozzle are of **the same magnitude as the propeller thrust.**

11. The forces **decrease rapidly with the increase of the distance from the nozzle**. Doubling the distance cuts the suction force to approximately 1/3.

12. In the blocked condition, the **nozzle develops a small fraction** of the propeller thrust, and the **nozzle thrust is directed aft** (including the suction force).

13. The suction force on the blocking piece at 90% of the power, placed 5 cm ahead of the nozzle mouth, is of the same magnitude as the **drag on that piece at a velocity of 11** knots.

### VIBRATION LEVELS

14. The thrust, torque and nozzle **vibration levels are** significantly **increased** from the non-blocked condition.

15. Shaft longitudinal vibrations are not related to shaft torsional vibrations.

16. Nozzle axial vibrations are not coupled with the nozzle torsional vibrations.

## 12 RESULTS OF ANALYTICAL CONSIDERATIONS

1. The amount of ice in the stern area (VL remain) is proportional to the velocity (V) of the ship:

$$\text{VL remain} = c1 * V - c2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{E.7}$$

where c1 and c2 are the proportionality constants.

2. **There exists a certain velocity below which there is no ice** in the stern and propeller area.

3. Propeller/nozzle **suction pressure is proportional to the thrust of the system**. This relationship was confirmed during the blockage tests.

4. The **suction pressure drops rapidly with the increase of the vessel speed.** This was also confirmed by the tests.

5. **Suction of propeller/nozzle system can not pull the free floating ice blocks down.** This would require the air suction from the surface to occur first.

6. ***The highest drop of pressure is above the propellers.***

7. *Several indicators can be used in order to estimate the amount of ice flow into the propeller area, in the ahead motion. Among them:*

*beam / girth length*
*waterplane area / wetted surface area*
***B * HP / (LOA *T)***........................*E.8*

*where:*

*B is the ships beam,*
*LOA is the ship's length overall*
*T is ship's draft*
*HP is the power delivered to the propellers*

*LSSL has a moderate value of this indicator (**643**), the highest being that for the Polar Star class ship (**1313**) and the lowest being that for the MV Arctic (**106**).*

8. *The **velocity of submergence of ice is large (60%** of the advance velocity) at the bow and at the stern of the LSSL. This means that ice blocks "slap" the hull when they are being submerged, and that the stern pushes ice blocks down vigorously into the propeller area.*

9. *Much improvement can be made to the stern design of LSSL.*

## *13 RESULTS OF TESTS IN ICE - FIRST SERIES*

*PERFORMANCE OF THE NOZZLE/PROPELLER SYSTEM*

1. *The performance of the centerline propeller and nozzle, as well that of the wing propellers, **was inferior** when compared to the performance **in ice free waters**. One reason for this was a necessity to reverse the RPS when a heavy block/propeller interaction occurred.*

*MAJOR INTERACTIONS*

2. *The port shaft saw the least of major interactions, **the** starboard shaft the most, and the center shaft the average between the two.*

3. ***Ahead mode of operations saw 10 times less interactions per meter travelled than the astern mode.***

4. *The frequency of major interactions is proportional to ship speed, in both ahead and astern modes of operations.*

5. *In both modes of operations, there is a **certain minimum speed, below which no interactions** take place between the propellers*

and ice. The number of interactions per second can be expressed as:

$$NOMI = A + B * V \quad \text{E.9}$$

where A and B are constants and V is the ship speed.

IMPACTS ON THE NOZZLE

6. Major impacts sharing between the shafts is speed independent.

7. The **number of impacts on the nozzle is power independent.**

8. The **reversed RPS lead to the high number of impacts** of the nozzle.

9. The **reduced draft resulted in the increase** of the number of interactions.

10. Within the range tested, ice coverage is not correlated with the number of interactions.

IMPACT FORCES

11. The **largest impact force on the nozzle was 645% (1,500 N)** of the system's bollard thrust. It occurred in the astern mode of operation, at a reduced draft.

12. **All large magnitude impacts occurred when ship was going astern.**

13. Lighter draft of the vessel leads to the higher magnitude forces.

14. There is no clear correlation between the magnitude of the impact forces and ice coverage.

15. **High impact forces are linked with the low average power levels.**

16. There is no strong correlation between the mean thrust and the maximum impact force level.

17. Above considerations lead to the conclusions that the frequency and magnitude of interaction forces **are geometry related, that is they depend on the hull and shaft configurations** and the proximity of the ice field, **not on the suction ability of the propulsors.**

18. Low speeds generate highest impact forces.

## STATISTICS OF THE SHAFT TORQUE AND THRUST

19. The maximum and minimum values of the torques recorded were proportional to the mean values developed during the runs.

20. The same applies to the thrust, except in the astern mode, where there is a weak correlation between the maximum and mean values.

## ICE FLOW

### Ahead motion

21. The **bow clears the ice pieces effectively**. At station 12 there is no ice in the bottom region.

22. The deepest submergence of the blocks reaches the region of the ice knife.

23. Emergence of ice blocks is **linked to the tumbling of the ice block envelope** surrounding the hull.

24. At a deep draft, there is little wing propeller/ice block interaction, as **most of ice pieces pass over the propellers.**

25. The ice pieces are sucked in by the stern, rather than the propellers, and they come from the sides of the ship not the bottom.

### Astern motion

26. In this mode of operations, ice is pushed down into the propellers by the stern.

27. Ice blocks wedge between the hull and:

**rudder post,**
**nozzle upper surface**
**wing bossing skegs.**

28. The **wedging** of the blocks on the wing propeller bossings is **very pronounced** and leads to the creation of frequent pile-ups in the stern area and severe ice/propeller interactions. This wedging is partially due to the **inward turning propellers** (in this mode of operations).

29. **Wing propellers rotate inward in the astern mode of operations pushing ice downward along the hull**. Outward rotation would result in less interactions and lower forces.

30. Lower draft leads to the **massive presence of ice blocks in the stern/propeller area.**

31. The stern of the ship piles up the free floating ice blocks and pushes those in front of it.

NOZZLE/ICE BLOCKS INTERACTIONS

32. The following modes of interactions were recorded during the tests:

    single impacts
    interactions with the nozzle support
    blockages
    milling
    indirect interaction

Indirect interactions are the result of the wing propellers reversals due to the milling of ice blocks, which results in a significant disturbance of the hydrodynamic condition of the nozzle/propeller system

33. **Only two cases of blockage** of the nozzle were recorded during this test series:

    one in the astern operations, and
    one at the reduced draft ahead, speed 10 knots.

This very limited amount of the blockage is due to:

    good ice clearing capability of the bow

    wing propellers and their wash providing an effective force against ice blocks moving around the nozzle
    deep draft of the vessel.

ICE BLOCKS/HULL INTERACTION

34. The hull of the vessel moving in a broken ice field compresses and moves the blocks ahead of itself creating an artificial high density zone in the bow or stern area.

35. Ice blocks are submerged when the frame angles (measured to horizontal) are small, and are pushed aside when the frame angles are large.

36. There is a **high pressure area on the bow** right above the ice knife (station 17)> This area extends from the stem to station 16 and from the above waterline to the 60% of the vessel draft.

37. All appendages at the stern show large number of heavy interactions with the blocks.

38. **Bottom of the nozzle shows the evidence of interactions** with the blocks. So does the bottom of the rudder.

*This is most likely due to the fact that the wings propellers* ***kick ice blocks down below the keel*** *when operating in the astern mode.*

39. *Wing propeller bossing skegs show pronounced marks of ice blocks sliding along.*

40. ***Stern area shows the traces of much more heavy interactions with blocks than the bow area.***

## 14. RESULTS OF OVERLOAD TESTS WITH THE DEFLECTOR

1. ***There is no measurable difference in the propulsor efficacy*** *at 100% RPS in the bollard and ahead condition with and without the deflector.*

2. *At lower powers developed, the deflector leads to the* ***lowering of the propulsor efficacy in the ahead and astern*** *condition.*

## 15. RESULTS OF TESTS IN ICE WITH DEFLECTOR

1. *Maximum impact forces on the nozzle are higher when the nozzle propeller operates than when the power is off, at the reduced draft.*

2. *The ratio of the extreme impact forces in powered condition to those in not powered condition is 2:1.*

3. ***The extreme thrust o****n the centerline shaft recorded was approximately* ***10 times*** *the propeller bollard thrust and 1.8 times the maximum nozzle impact force.*

4. *The extreme value of the torque recorded was* ***12.5 times*** *the bollard hydrodynamic torque, for the conditions tested.*

5. *The maximum values of the centerline propeller torque and thrust diminish with the increase of model speed.*

6. ***All of the high impact forces on the nozzle were recorded in the astern or near bollard condition.***

7. *The maximum impact force on the nozzle was* ***552%*** *of the nominal combined bollard thrust of the system.*

8. ***At high model speeds ahead the impact forces were low, if any.***

9. *The* ***magnitude of the impact forces on the nozzle decrease*** *wit an increase of model speed.*

10. The degree of ice coverage is not correlated strongly with the magnitude of impact forces.

11. Lower draft leads to higher impact forces. There is no clear trend between the magnitude of the forces and the draft.

12. The extreme nozzle impact forces are effectively located **at $r/R = 0.25$** above the nozzle axis.

13. There are a number of impacts located below the nozzle axis, especially when going astern. This is confirmed by the wax marks on the lower part of nozzle mouth.

14. Smaller ice blocks enter the nozzle mouth and create the blockage/milling condition.

15. When comparing this test results with the previous tests in ice, the following general conclusions can be drawn:

TABLE EXEC3
Comparison of the main test results

| Test conditions | Number of interactions | Blockages |
|---|---|---|
| deep draft<br>large pieces | small | few |
| light draft<br>small pieces | high | many |

COMPARISON WITH THE FULL SCALE DATA

The twin shaft Polar Stern (draft 10.5 m) has two nozzles of the same diameters as the centerline nozzle of LSSL. Therefore we will compare the nozzle impact loads described in References 14 and 15 fore that ship with the test results. Table 16.3 shows the comparison.

TABLE EXEC4
Comparison of the test results with the full scale data

| Vessel | condition | nozzle impact forces |
|---|---|---|
| This series | astern | 516 tonnes |
| This series | ahead | 104 tonnes |
| Polar Stern | astern | 210 tonnes |
|  | ahead | 120 tonnes |
| Nozzle design force |  | 780 tonnes |

*Thus we can conclude that the results of the tests were comparable with the full scale data of a similar ship, and that the **forces recorded are within the design capability of the nozzle.***

## *16 Conclusions*

*The **main** conclusions are:*

1. *Shrouded propeller system installed on the centerline shaft of the model of CCG Louis S. St Laurent produced hydrodynamic performance at speeds below 15 knots **far superior** to the unshrouded propeller. The thrust gain at the bollard ahead is approximately 35%, and at the bollard astern it is 70% of the bollard thrust ahead, for the same power delivered.*
2. *There is a **significant hydrodynamic interference** between the wing propellers and the centerline propeller, resulting in the large change of the performance of the system.*
3. *At a full draft and ahead speed **the frequency of blockage** of the centerline shaft with large blocks of broken ice **is very low.***
4. *The astern motion causes the **order of magnitude increase** of ice/propeller and ice/nozzle interactions.*
5. ***Decreasing the draft and decreasing the size** of the ice blocks **increases** significantly the frequency of ice/propellers and ice/nozzle interactions.*
6. ***Ice blocks jam frequently** against the hull and the bossings of the wing propellers, in the **astern operations.***
7. ***Inward turning propellers** in the astern mode push ice blocks against the hull and down the center skeg creating the jamming and nozzle impact/blockage potential.*
8. *Ice/propeller interaction is the result of the hull/ice interaction rather than the result of ice suction action by the propellers, especially in the astern mode of operation.*
9. *Ice blocks moving in water exhibit the "critical speed" property, that is their motion is de-stabilized and slowed down when that speed is exceeded. Pushing ice blocks aside should be done below the critical speed.*
10. *The most severe blockage scenario is in the ahead mode of operation and with the middle of the nozzle blocked.*
11. *Waterjets produce a significant force on a target and can be used as an ice deflecting mean.*

12. The novel technique of modeling the broken ice field by means of wax blocks was found to be suitable and successful.

13. Turning of an ice block adjacent to the wall (shell) takes four times longer than the turning up of an isolated block.

## 17 Recommendations

We recommend the following:

DESIGN/OPERATIONAL RECOMMENDATIONS

- The centerline propeller on the triple screw icebreakers be shrouded.
- The design of the wing skegs and the direction of the rotation of the wing propellers be changed in the light of the findings of this project.
- The ship be operated at the maximum draft, especially when the astern mode of operations is used frequently.
- The stern area of the vessel be redesigned in order to minimize the ice ingestion into the propellers in the astern mode of operations. The redesign may include the hull form and/or addition of the new appendages, like deflectors/sponsons/skegs etc.
- The nozzle mouth be redesigned to minimize the effects of the middle part blockage (the most severe blockage condition), by means of the blisters. These can be installed at the fore and aft ends of the nozzle.
- The bow of the vessels contain the "step" or another means of breaking up the envelope of ice, thus permitting it to float up sooner.
- The deflectors be structurally capable of sustaining very large ice impact forces in the vertical direction.
- The design of the ice deflecting devices reflect the "critical speed" onset of the blocks, beyond which pushing aside of the ice blocks is not effective. Gradual and prolonged pushing action is recommended rather than a quick and forceful.
- Use of waterjets as a mean of deflecting the ice from the propeller area be considered. They should be applied to the astern operations in particular.

- *When designing the shrouded propeller, its hydrodynamic characteristics be made tolerant to the large wake fluctuations in the blockage conditions.*

- *The design of the propeller and nozzle system account for the forces and vibrations of the system in the blockage conditions.*

*FUTURE R&D*

*A test programme be established to test the effect of waterjets on the clearing of ice, in particular from the stern of the icebreaker in the astern mode of operations.*

*That the series of the sterns is designed and tested with regard to ice clearing from the propeller disk area.*

*The the interference of the wing propellers with the center one be tested and the optimum configuration established.*

# SOMMAIRE

## 1. Introduction

Sur les navires navigant dans les glaces, les tuyères d'hélice offrent deux avantages marqués :

- Accroissement de la poussée pour un même niveau de puissance

- Protection des hélices

Mais ils ont l'inconvénient d'être parfois obstrués par des fragments de glace.

La présente recherche a eu pour but d'approfondir le phénomène de blocage et d'étudier des techniques pour le prévenir.

Pour étudier ce phénomène et l'écoulement des fragments de glace, les chercheurs ont utilisé une maquette 1:15 du brise-glace Louis Saint-Laurent, équipée d'une tuyère protégeant l'hélice centrale. Quant aux modalités de la recherche : programme des essais, matériel et instrumentation, elles ont été axées sur l'objectif à atteindre.

## 2. Objectifs de la recherche

La recherche a eu les objectifs suivants :

- Étudier l'écoulement des fragments de glace passant sous la coque et se dirigeant vers l'entrée de la tuyère

- Étudier l'influence du blocage sur la puissance, le couple moteur et la poussée produits par l'hélice sous tuyère

- Déterminer l'évolution des performances du système hélice-tuyère en fonction du blocage

- Proposer une solution permettant de réduire l'influence du blocage au minimum, (évaluer celle des jets d'eau, par exemple).

## 3. Plan de recherche

La recherche a commencé par un tour d'horizon des techniques d'étude concernant le blocage des tuyères et les phénomènes connexes et a débouché sur un programme d'essais en deux phases :

### Phase 1

- essais préliminaires sur les propriétés des glaces et essais de propulsion en eau libre

- essais dans les glaces
- mise en oeuvre des jets d'eau

Phase 2

- essais préliminaires à l'aide d'un dispositif anti-blocage
- essai de ce dispositif par simulation d'un champ de glaces

Les résultats de la phase 1 ont débouché sur la réalisation d'un dispositif anti-blocage. La phase 2, par contre, n'a connu qu'un succès partiel pour des raisons reliées à une liaison déflecteur-coque défectueuse et à l'hélice qui a été endommagée.

## 4. Recherche documentaire

Cette recherche a permis de trouver 15 documents traitant de recherches théoriques et d'essais en vraie grandeur et sur maquette concernant le phénomène du blocage des tuyères d'hélices par les glaces. Tous ces documents indiquent que le blocage produit :

un accroissement de la poussée produite par l'hélice
un accroissement du couple produit par l'hélice
une diminution de la poussée attribuable à la tuyère
de fortes vibrations du système

Les plus fortes variations de la poussée de l'hélice ont été observées durant les essais en vraie grandeur à bord du Robert-LeMeur (4,7 fois la poussée hydrodynamique). Quant au couple moteur maximum observé, il a été le double du couple à la puissance maximale continue au point fixe.
Certains de ces documents ont précisé les avantages que les tuyères procurent, par rapport aux hélices qui n'en sont pas équipées. Dans le cas de l'hélice centrale du Louis Saint-Laurent, les valeurs suivantes ont pu être dégagées par l'auteur :

| | |
|---|---|
| Poussée du système protégé/non protégé en marche avant à 3 noeuds | 1,38 |
| Poussée au point fixe en marche arrière (système protégé/non protégé) | 1,58 |
| Vitesse maximum réalisable (système protégé/non protégé) | 0,99 |
| Risque de cavitation (système protégé/non protégé) | faible/fort |
| Rapport poussée/puissance maximum au point fixe en marche avant | 17kg/Hp |
| Rapport poussée/puissance maximum au point fixe en marche arrière | 14 kg/Hp |
| Rapport poussée/puissance moyen au point fixe en marche avant | 11,4 kg/Hp |

Tous les ouvrages signalent le blocage de la tuyère par les glaces, notamment dans le cas de navires à faible tirant d'eau. Mais aucun ne signale la rupture d'une pale d'hélice sous tuyère attribuable aux glaces.

Les forces d'impact les plus fortes dues aux heurts des glaces contre la tuyère ont été signalées à l'égard du Polar Stern qui est équipé d'une tuyère de diamètre comparable à celle du Louis Saint-Laurent :

210 tonnes en marche arrière
120 tonnes en marche avant

La force d'impact de calcul de la tuyère centrale à été déterminée comme étant de 780 tonnes.

Les essais sur maquette ont permis les observations suivantes, consécutives à un blocage par les glaces :

- les valeurs moyennes de poussée et de couple moteur ont crû de 220 à 250 p. 100 par rapport aux forces hydrodynamiques moyennes en régime stationnaire

- L'excursion crête-à-crête :
  de la composante axiale de l'effort sur la pale de l'hélice
  a augmenté de 1 000 p. 100 du couple moteur a augmenté de
  130 p. 100 de la poussée a augmenté de 100 p. 100
  du couple de torsion de pale a augmenté de 3 400 p. 100
  des moments de flexion sur arbre ont augmenté de 700 p. 100

L'équipe chargée des essais sur maquette met en garde contre les difficultés de mesurage et de suivi des expérimentations résultant des fortes vibrations que suscite une tuyère bloquée par les glaces.

Une chute brutale des efforts induits par le blocage est signalée lorsque le fragment se trouve à une certaine distance de l'entrée de la tuyère.

Les paramètres qualifiés d'importants dans la détermination de la fréquence d'interaction hélice-glace ont été les suivants :

Géométrie de la coque
Longueur du navire
Tirant d'eau et bau
Aplatissement du fond
Nombre d'arbres et leur configuration
Profondeur de submersion de l'hélice
Puissance à l'arbre
Vitesse et
Conditions glacielles
Les ouvrages consultés font état des techniques suivantes

permettant de prévenir les blocages ou d'en atténuer les effets

- dispositifs déflecteurs : ailerons, déflecteurs, cages
- dérivations : fentes dans le bâti annulaire de tuyère, par exemple
- jets d'air injectés dans la tuyère

## 5. Programme des essais

La maquette a été remise en état, renforcée et équipée d'une hélice centrale sous tuyère. Une grande quantité de glace-modèle en cire a été fabriquée. Une digue a été construite pour retenir les fragments de glace-modèle. Un jet d'eau complété d'une chaîne de mesure dynamométrique a été installé au préalable. L'arbre du milieu a été équipé d'un nouveau dynamomètre plus résistant aux efforts suscités par les blocages. Les essais suivants ont été menés :

TABLEAU EXEC1

SOMMAIRE DES ESSAIS

| Description | Objet |
|---|---|
| Essai d'émergence | Déterminer les propriétés hydrodynamiques des fragments |
| Essais de frottement | Détermination de la composante frottement dans les interactions inter-fragments et coque-glaces |
| Essais avec jets d'eau | Observer l'efficacité des jets d'eau dans l'éloignement des fragments et la prévention du blocage |
| Essais de surcharge | Déterminer les caractéristiques propulsives de la maquette équipée d'une hélice sous tuyère et en eau libre |
| Essais de blocage | Déterminer les efforts induits par le blocage et les caractériser |
| Essais dans les glaces sans déflecteur | Étudier l'écoulement des fragments et caractériser les interactions fragments-hélice sous tuyère, en fonction des paramètres définis |
| Essais de surcharge avec déflecteur | Étudier les variations des caractéristiques en eau libre de la maquette équipée d'un déflecteur |
| Essais dans les glaces | Comparer le comportement du système hélice - tuyère avec et sans déflecteur |

Étant donné que le bassin des glaces n'était pas disponible, les essais sur maquette ont été menés dans un bassin des carènes ordinaire, dans lequel ont été placés des fragments de glace-modèle en cire.

Cette glace-modèle s'est révélée plus que satisfaisante, possédant des propriétés de flottabilité et de frottement convenant très bien aux essais. Sa résistance, cependant, a été trouvée trop élevée, et difficile à maîtriser avec les moyens disponibles.

La maquette réalisée en mousse renforcée de fibres de verre s'est révélée trop fragile et trop flexible pour les besoins des expérimentations. La trop grande flexibilité a rendu difficile un alignement précis de la ligne d'arbres et le mesurage des signaux correspondants. La résistance des liaisons coque-appendices s'est révélé trop faible, menant à la destruction du déflecteur lors de l'ultime série des essais.

## 6. RÉSULTATS DES ESSAIS D'ÉMERGENCE

1. Le temps d'émergence est proportionnel à la profondeur de submersion.

2. Les fragments remontant à la surface atteignent rapidement la vitesse limite de remontée, qui ne varie pas pour un même fragment.

3. Cette vitesse limite, $V_{cr}$, varie selon :

l'épaisseur du fragment $H_i$
le rapport densité de la glace-modèle par rapport à l'eau, row/roi
le coefficient de traînée cr
l'accélération due à la pesanteur g

$V_{cr}$ = (2*g*Hi*(row/roi-)/cr)^0.5........................E.1

4. Les équations indiquées décrivent bien la dynamique d'émergence d'un fragment libre.

5. Les fragments ont un mouvement oscillatoire stable.

6. Les temps d'émergence est d'autant plus court que le fragment est lourd.

Pour une profondeur de 1,6 m et pour les tailles considérées :

Temps d'émergence = 14,8 - 1,898 x masse du fragment.......E.2

7. Une surface en pointe émerge plus rapidement qu'une plate.

8. L'équation suivante permet une approximation de la distance parcourue par un fragment remontant à la surface :

   z(t)=a + Vcr *t .................................... E.3

   où a constante pour un fragment donné est $V_{cr}$ la vitesse limite

9. Le coefficient de la masse entraînée pour un fragment est d'environ 4.

10. Plus le fragment est épais, moins le coefficient de traînée est élevé.

11. Le temps d'émergence d'un fragment se trouvant au bord du bassin est approximativement quatre fois celui d'un fragment libre.

12. Le temps d'émergence d'un fragment lâché près du fond de la maquette décroît à mesure que s'accroît sa masse.

13. Pour le fragment considéré, le temps d'émergence moyen à partir du fond de la maquette a été de 2 s. Le temps le plus élevé correspond à la partie médiane de la coque.
14. Dans le cas d'un fragment soumis à une accélération brutale, la vitesse moyenne est inversement proportionnelle à l'accélération initiale.

15. Il existe une vitesse critique, au-delà de laquelle un fragment devient instable et commence à ralentir.

16. Pour imprimer à des fragments un mouvement les éloignant le plus possible de la coque, il faut les accélérer graduellement sans dépasser la vitesse critique. Il faut éviter les accélérations brutales.

## 7. RÉSULTATS DES ESSAIS DE FROTTEMENT

- La glace-modèle en cire possède des propriétés de frottement très proches de celles tirées des expérimentations en vraie grandeur et à faible pression de contact/INERTA 160.

- La méthode de mesurage utilisée est pratique, donnant des résultats cohérents, parce qu'elle tient compte des phénomènes physiques conditionnant l'interaction entre les fragments submergés et la coque.

- Le coefficient de frottement cire-coque mesuré est de 0,24; il varie légèrement avec l'état et la condition de la surface de la coque.

- Le coefficient de frottement ne varie pas avec la masse des fragments, sauf s'il existe une très légère réduction de poids dans le cas de deux fragments en cire mouillés, représentant un frottement inter-fragments.

- La présence d'eau a fait que le coefficient de frottement Inter-fragments a augmenté de 0,21 à 0,28.

- Le coefficient de frottement cire-coque est plus faible qu'entre deux fragments : 0,24 par rapport à 0,28.

## 8. RÉSULTATS DES EXPÉRIMENTATIONS AVEC UN JET D'EAU

### Généralités

1. La méthode utilisée a permis d'obtenir des informations utiles concernant la poussée du jet sous la surface de l'eau.
   Poussée maximale mesurée : 26,4 N
   Puissance maximale produite par le jet : 440 watts

2. Les lois de similitude (nombre de Froude) permettent l'extrapolation des résultats théoriques aux valeurs en vraie grandeur :
   La poussée du jet d'eau s'accroît proportionnellement à
   La puissance du jet d'eau s'accroît proportionnellement à

### Calculs analytiques

1. Il est possible de calculer la force du jet par la sommation de ses composants statique et dynamique. Les résultats sont valables.

2. Les calculs à l'aide de l'équation ci-dessous donnent une bonne approximation dans toute la plage des expérimentations

   F = 1025 x V^2 x surface de l'entrée....................E.4
   (toutes les dimensions sont en unités SI)

3. La force exercée sur un fragment peut se calculer en première approximation, utilisant l'équation précédente, comme suit :

F = C x (4 x(puissance.du jet)^2 x ro x section de l'ajutage)^1/3....................................E6.5

où C coefficient de la distance obtenu de :

C = 1,03 - 0,3343 x distance...............................E.6

Cette équation n'est valide que dans la plage des puissances expérimentées.

Force maximale/distance

La force exercée sur un fragment est inversement proportionnelle à la distance.
La force faiblit légèrement dans le cas d'un ajutage de section moyenne ou forte, et fortement si l'ajutage est de petite section. La réduction est linéaire, dans la plage des valeurs expérimentées.

Force maximale/section d'ajutage

La force croît proportionnellement à la section d'ajutage, jusqu'à une valeur limite conditionnée par la pression d'alimentation

Force maximale/pression

La force maximale exercée sur un fragment croît plus ou moins proportionnellement à la pression à l'intérieur du système.
Force maximale/médium
La force maximale dans l'eau est supérieure à celle dans l'air.

Efficacité du système

Les ajutages qui ont servi aux expérimentations étaient de conception simple, leur comportement hydraulique a été analogue à celui d'un orifice dans un réservoir à paroi mince.
Le coefficient d'efficacité (poussée/puissance) moyen (dans toute la plage des expérimentations) du jet croît proportionnellement et linéairement avec la section de l'ajutage.
Pour la tuyère médiane testée, l'efficacité moyenne a été de 6,15 kg/Hp.

## 9. RÉSULTATS DES ESSAIS DE SURCHARGE

1. L'hélice centrale sous tuyère développe 11,4 kg/Hp (vraie grandeur), soit une valeur de plus de 35 p. 100 supérieure à la valeur obtenue avec une hélice non protégée, au point fixe.

2. La poussée en marche arrière au point fixe est à peu près égale à celle en marche avant au point fixe, pour un même régime (tr/s).

3. La valeur élevée de poussée en marche arrière, développée par le système (70 p. 100 de celle au point fixe en marche avant), se maintient même à la vitesse de 6 noeuds en marche arrière.

4. Cette constatation confirme pleinement les résultats présentés dans la référence bibliographique 1.

5. La tuyère contribue plus de poussée que l'hélice au point fixe en marche avant.

6. L'emplacement du vecteur de poussée de la tuyère varie en même temps que la charge elle-même, notamment celle en direction verticale.

7. Ce vecteur se situe la plupart du temps au-dessous de l'axe longitudinal de la tuyère.

8. Le système hélice-tuyère central contribue plus du tiers de la poussée combinée des trois arbres, pour un même régime (tr/s) et pour toute la plage des conditions expérimentées (de 40 à 60 p. 100 du total)

9. Pour ce système central, le facteur de succion est de 0,23 au point fixe en marche avant, les hélices d'extrémité étant arrêtées.

10. Ce facteur a été de 0,32 au point fixe en marche arrière.

## 10. VARIATIONS DE LA POUSSÉE DUES AUX HÉLICES D'EXTRÉMITÉ

1. Les données obtenues permettent de conclure que les hélices d'extrémité perturbent profondément le fonctionnement de l'hélice centrale sous tuyère.

2. En marche avant toute, on peut s'attendre à un gain considérable de poussée développée par la tuyère, par analogie à ce qui se passe avec des pompes axiales travaillant en série. En marche arrière, la poussée du système central risque d'être considérablement affaiblie, pour cette même raison.

## 11. RÉSULTATS DES ESSAIS DE BLOCAGE

Caractérisation du phénomène :

1. Un blocage entraîne les conséquences suivantes (pour un

même régime tr/s) :

Accroissement de la poussée sur arbre
Accroissement du couple moteur sur arbre
Réduction de la poussée attribuable à la tuyère
Réduction de la poussée totale
Augmentation de la puissance absorbée
Réduction de l'effort sur le câble de traction
Augmentation des niveaux vibratoires de la chaîne cinématique : tuyère, hélice et lignes d'arbres

2. Un blocage de la tuyère s'apparente, sur le plan hydrodynamique, au cas d'un navire avançant à une certaine allure en eau libre alors que l'hélice travaille dans un sillage puissant, c'est-à-dire que la vitesse d'avance de l'hélice est de beaucoup inférieure à celle du navire (il y a parfois même vitesse d'avance négative), bien que le sens de sa rotation soit celui de la marche avant.
Comportement du système hélice-tuyère en situation de blocage

3. La plus forte chute de poussée produite par la tuyère a été observée lorsqu'il y a eu blocage dans la partie centrale de la tuyère et que les trois hélices étaient en rotation : de + 65 p. 100 à -50 p. 100 de la poussée totale au point fixe, correspondant respectivement à l'état de tuyère entièrement dégagée, et engorgée dans sa partie centrale. Une légère amélioration a été constatée dans la poussée produite par la tuyère lorsque le dispositif a été placé à quelque 10 cm à l'amont de la tuyère.

4. Le blocage de la partie centrale de la tuyère a entraîné une chute variant de 100 à 25 p. 100 environ dans les paramètres de rendement tel que le rapport effort de traction/puissance à l'arbre ou poussée totale/puissance à l'arbre.

5. La chute la plus forte dans le rapport effort de traction/puissance à l'arbre a été observée lors du blocage de la partie centrale de la tuyère et la moins forte lorsque le dispositif a été placé à 10 cm à l'avant de la tuyère. Sur le plan du rapport effort de traction/puissance à l'arbre, les résultats ont été les suivants :

TABLEAU EXEC.2

Sommaire des résultats observés

| RÉSULTATS | PUISSANCE AU POINT FIXE | | SURFACE BLOQUÉE |
|---|---|---|---|
| | MARCHE AVANT | MARCHE ARRIÈRE | |
| Très bons | Aucun blocage | Aucun blocage | 0 % |

| | | | |
|---|---|---|---|
| | 10 cm à l'avant | - | |
| | Partie supérieure bloquée | Partie supérieure bloquée | 20% |
| | Partie inférieure bloquée | Partie inférieure bloquée | 23% |
| | 5 cm à l'amont | - | |
| Très mauvais | Partie centrale bloquée | Partie centrale bloquée | 47% |

6. Les hélices d'extrémité multiplient l'effet du blocage en augmentant la traînée produite par le fragment bloquant et en diminuant d'autant la poussée totale attribuable à la tuyère.

7. L'allure du navire a un effet nettement négatif sur le rapport poussée/puissance lorsqu'il y a blocage.

8. En marche arrière, le blocage a eu des effets moins sentis qu'en marche avant.

SUCCION

8. La succion sur le fragment à l'amont de la tuyère est fortement liée à la valeur de la poussée de l'hélice.

9. Elle diminue lorsque la vitesse augmente.

10. La succion agissant sur un fragment à 5 cm à l'amont de la tuyère et la poussée de l'hélice ont le même ordre de grandeur.

11. La succion décroît rapidement avec l'accroissement de la distance par rapport à la tuyère : elle décroît du tiers environ lorsque la distance est doublée.

12. Lorsqu'il y a blocage en marche avant, la tuyère ne produit plus qu'une faible fraction de la poussée produite par l'hélice et cette poussée est dirigée vers l'arrière (y compris la succion).

13. A environ 90% de la puissance, la succion agissant sur le fragment à 5 cm à l'amont de la tuyère et la traînée produite par ce fragment à 11 noeuds ont le même ordre de grandeur.

## NIVEAUX VIBRATOIRES

14. Les niveaux vibratoires occasionnés par le blocage de la tuyère augmente considérablement par rapport à l'absence de blocage.

15. Les vibrations longitudinales de l'arbre ne sont pas liées aux vibrations torsionnelles de celui-ci.

16. Les vibrations axiales de la tuyère ne sont pas liées, non plus, aux vibrations torsionnelles de cette dernière.

## 12 RÉSULTATS DE L'ÉTUDE ANALYTIQUE

1. La quantité de fragments dans la partie arrière (volume résiduel VL) est proportionnelle à la vitesse V du navire selon l'équation suivante :

$$VL = C1 * V - C2 \quad \text{.........................E.7}$$

où c1 et c2 sont des coefficients de proportionnalité

2. Au-dessous d'une certaine vitesse, on ne trouve plus de fragments dans la partie arrière ni au droit des hélices.

3. La succion produite par le système hélice-tuyère est proportionnelle à la poussée de celui-ci, relation confirmée par les essais de blocage.

4. La succion décroît rapidement avec l'accroissement de la vitesse, relation également confirmée par les essais.

5. La succion produite par le système hélice-tuyère ne suffit pas à aspirer les fragments flottants à la surface vers le fond, à moins que l'air entourant ces fragments ne soit aspiré d'abord.

6. La chute de pression la plus forte a été observée au-dessus des hélices.

7. Parmi les paramètres permettant de prédire la quantité de fragments aspirés par le système propulsif du navire en marche avant, on relève les suivants :

rapport bau/périmètre
rapport surface de remplissage à la flottaison/surface mouillée
rapport bau x Hp/longueur hors tout x tirant d'eau

$$B * HP /(LOA * T) \quad \text{..................................E.8}$$

où Hp est la puissance de propulsion

Le Louis Saint-Laurent affiche une valeur modérée (643) par rapport aux navires de classe Polar Star (1313) et le N.M. Arctic (106) qui occupent les extrêmes de la plage de variation de ce paramètre.

8. La vitesse de submersion des fragments est élevée (60 p. 100 de la vitesse de marche) tant à la proue qu'à l'arrière du Louis Saint-Laurent. Il en résulte que les fragments heurtent violemment la coque au moment de leur submersion et qu'ils sont repoussés par l'arrière avec force vers le système propulsif.

9. La partie arrière du Louis Saint-Laurent gagnerait beaucoup à être réétudiée.

## 13.RÉSULTATS DES ESSAIS DANS LES GLACES - SÉRIE I

### COMPORTEMENT DU SYSTÈME HÉLICE-TUYÈRE

1. Dans les glaces, le rendement des hélices centrales et d'extrémité a été moindre qu'en eau libre, décroissance attribuable en partie à l'inversion de marche qu'il fallait faire chaque fois qu'un heurt violent se produisait entre un fragment et l'hélice.

### PRINCIPALES CONSTATATIONS

2. Le plus grand nombre de heurts violents a eu lieu avec l'arbre de tribord, le plus petit avec l'arbre de bâbord et un nombre moyen avec l'arbre central.

3. Il y a eu 10 fois moins de heurts par mètre parcouru en marche avant qu'en marche arrière.

4. La fréquence de heurts violents est proportionnelle à la vitesse, tant en marche avant qu'en marche arrière.

5. Dans les deux sens de marche, il existe une vitesse minimale au-dessous de laquelle il ne se produit aucun heurt entre les hélices et les fragments. Le nombre de heurts par seconde peut se calculer comme suit :

$$\text{NOMI} = A + B \times V \quad \text{................E.9}$$

où A et B sont des constantes et V la vitesse du navire.

### INTERACTIONS TUYÈRE-GLACES

6. La distribution des heurts violents entre les arbres ne

dépend pas de la vitesse.

7. Le nombre d'impacts sur la tuyère n'est pas conditionné par la puissance.

8. En marche arrière, le nombre d'impacts sur la tuyère augmente.

9. Une réduction du tirant d'eau augmente le nombre d'impacts.

10. Dans la plage des conditions expérimentées, il n'y a aucune corrélation entre la couverture de glace et le nombre d'impacts.

FORCE DES IMPACTS

11. La force d'impact la plus élevée a été de 645 p. 100 (1 500 N) de la poussée au point fixe. Elle a été observée en marche arrière avec un tirant d'eau réduit.

12. Tous les impacts d'amplitude élevée se sont produits en marche arrière.

13. Une réduction du tirant d'eau se traduit par des impacts dont l'amplitude est parmi les plus élevées.

14. Aucune corrélation évidente entre l'amplitude des impacts et la couverture des glaces.

15. Il y a un lien entre impacts d'amplitude élevée et valeurs réduites de puissance moyenne.

16. Aucune relation évidente entre poussée moyenne et amplitude maximale des impacts.

17. Ces constatations mènent à la conclusion que les impacts, en fréquence et en amplitude, sont conditionnés par la géométrie de la coque, par la configuration du système propulsif et par la proximité du champ de glace et non par la succion produite par les hélices ou la tuyère.

18. Les impacts de plus forte amplitude se produisent aux faibles vitesses.

STATISTIQUES SUR LA POUSSÉE ET LE COUPLE MOTEUR

19. Les valeurs maximale et minimale de couple moteur observées sont proportionnelles aux valeurs moyennes tirées des essais.

20. Il en va de même de la poussée, sauf en marche arrière où la corrélation entre valeurs maximale et moyenne est plutôt faible.

## PARCOURS DES FRAGMENTS

### Marche avant

21. La proue repousse la glace efficacement. Au droit de la section 12, le fond est complètement dégagé de fragments.

22. Les fragments sont entraînés à la profondeur de l'éperon.

23. L'émergence des fragments est conditionnée par le basculement de l'ensemble des fragments entourant la coque.

24. Lorsque le tirant d'eau est fort, l'interaction entre les hélices d'extrémité et les fragments est faible, étant donné que la plupart n'atteignent pas le niveau des hélices.

25. Les fragments sont aspirés par l'arrière du navire plutôt que par les hélices; ils proviennent de part et d'autre du navire et non du fond.

### Marche arrière

26. L'arrière du navire repousse les fragments vers les hélices.

27. Les fragments sont pris entre la coque et :
    l'étambot arrière
    la surface supérieure de la tuyère
    les talons supportant les bossages d'extrémité

28. Le coincement des fragments avec les bossages, très marqué, provoque de nombreux empilages à l'arrière et des impacts violents contre les hélices. Il est attribuable en partie au fait que en marche arrière les hélices tournent vers l'intérieur.

29. En marche arrière, les hélices d'extrémité tournent vers l'intérieur et aspirent les fragments vers la coque et le long de celle-ci. Une rotation dans le sens inverse réduirait les impacts et l'amplitude de ces derniers.

30. Un tirant d'eau faible provoque la présence massive de fragments à l'arrière dans la zone de propulsion.

31. L'arrière du navire provoque l'empilage des fragments en flottaison libre et pousse ceux qui se trouvent devant lui.

## INTERACTIONS TUYÈRE-GLACES

32. Les interactions enregistrées durant les essais ont été recensées comme suit :

heurts simples
heurts contre le support de la tuyère
blocages
broyage
interactions indirectes
ces dernières résultant du renversement des hélices d'extrémité dû au broyage des fragments de glace et qui provoque une perturbation importante des conditions hydrodynamiques entourant le système tuyère-hélice.

33. Deux cas seulement de blocage de la tuyère ont été enregistrés durant cette série d'essais :
une fois en marche arrière et
une fois en marche avant à tirant d'eau réduit à la vitesse de 10 noeuds.

Cet effet anti-blocage est le résultat :

- d'une bonne géométrie de la proue qui éloigne les fragments de glace

- de la force produite par les hélices d'extrémité et par leur sillage et qui s'exerce efficacement sur les fragments qu'elle empêche de pénétrer dans la tuyère

- du grand tirant d'eau du navire.

## INTERACTIONS COQUE-GLACES

34. Dans un champ de glaces fragmentées, la coque du navire pousse les fragments devant elle en marche arrière comme en marche avant, créant une zone de haute pression à la proue ou à l'arrière, selon le cas.

35. L'angle des membrures (par rapport à l'horizontale) entraîne les fragments vers le fond lorsqu'il est petit, et les éloigne lorsqu'il est grand.

36. Il se crée une zone de haute pression sur la proue dans la zone juste au-dessus de l'éperon (section 17); elle s'étend depuis l'avant jusqu'à la section 16 et depuis la ligne de flottaison jusqu'à 60 p. 100 du tirant d'eau.

37. Tous les appendices à l'arrière subissent un nombre élevé de chocs violents contre les glaces.

38. Les heurts ont laissé des traces visibles sur le fond de la tuyère et du gouvernail. Il est probable que ces heurts sont dus au fait que les hélices d'extrémité repoussent les fragments au-dessous de la quille, lorsque le navire fait marche arrière.

39. Les talons supportant les bossages d'extrémité montrent des traces marquées de fragments ayant glissé tout au long.

40. Les traces de heurts violents contre des fragments de glace sont plus nombreuses à l'arrière qu'à l'avant.

## 14. ESSAIS DE SURCHARGE AVEC DÉFLECTEUR

1. Le rendement de la propulsion à plein régime au point fixe en marche avant est à peu près le même, avec et sans déflecteur.

2. Aux autres régimes, la présence du déflecteur réduit le rendement de la propulsion, en marche arrière et avant.

## 15. ESSAIS DANS LES GLACES AVEC DÉFLECTEUR

1. Avec un tirant d'eau réduit, les forces d'impact sur la tuyère sont maximales lorsque l'hélice correspondante est en marche.

2. Dans ce cas, les forces extrêmes sont le double de celles observées lorsque cette hélice est arrêtée.

3. La poussée maximale observée à l'arbre central a été à peu près 10 fois celle au point fixe et 1,8 fois la force maximale d'impact sur la tuyère.

4. La valeur extrême de couple observée a été 12,5 fois supérieure au couple hydrodynamique au point fixe, dans les conditions expérimentées.
5. Les valeurs maximales de couple et de poussée à l'arbre central diminuent à mesure qu'augmente la vitesse.

6. Toutes les valeurs élevées d'impact sur la tuyère ont été observées en marche arrière et proche du point fixe.

7. La force d'impact maximale sur la tuyère a été 552 p. 100 supérieure à la poussée totale au point fixe du système.

8. Aux vitesses élevées en marche avant, les forces d'impact

ont été faibles, sinon négligeables.

9. L'amplitude des forces d'impact sur la tuyère diminue à mesure qu'augmente la vitesse.

10. Il n'a pas été observé de forte corrélation entre la couverture des glaces et l'amplitude des forces d'impact.

11. Avec des tirants d'eau réduits correspondent des forces d'impact plus élevées, sans qu'une corrélation manifeste ait pu être dégagée entre ces deux paramètres.

12. Les valeurs extrêmes des forces d'impact ont été observées à une distance de r/R = 0,25 au-dessus de l'axe de la tuyère.

13. Un certain nombre d'impacts ont été observés au-dessous de cet axe, surtout en marche arrière, à preuve les marques laissées par la cire à l'entrée de la tuyère dans sa partie inférieure.

14. Ce sont les petits fragments de glace ayant pénétré dans la tuyère qui provoquent les conditions de blocage et de broyage.

15. La comparaison de ces essais dans les glaces avec les résultats des essais précédents, également dans les glaces, autorise les observations générales suivantes :

TABLEAU EXEC.3

Bilan comparatif des principaux résultats

| Conditions expérimentées | Nombre d'impacts | Blocages |
|---|---|---|
| Fort tirant d'eau<br>Fragments forte taille | peu élevé | rares |
| Tirant d'eau faible<br>Fragments petite taille | élevé | nombreux |

COMPARAISON AVEC LES ESSAIS EN VRAIE GRANDEUR

Les deux hélices du Polar Stern (tirant d'eau 10,5 m) sont protégées chacune par une tuyère de diamètre identique à la tuyère centrale sur le Louis Saint-Laurent. Ce qui nous autorise à comparer les charges d'impact observées sur les tuyères de ce navire, mentionnées dans les ouvrages référencés 14 et 15, avec les résultats tirés des essais sur maquette, voir le tableau 16.3.

TABLEAU EXEC.4

Comparaison des essais sur maquette avec ceux en vraie grandeur

| Navire | Condition de marche | Forces d'impact observées sur la tuyère |
|---|---|---|
| Maquette Louis Saint-Laurent | arrière | 516 tonnes |
| | avant | 104 tonnes |
| Polar Stern | arrière | 210 tonnes |
| | avant | 120 tonnes |
| Résistance nominale de la tuyère | | 780 tonnes |

On constate que les résultats des essais sur maquette sont comparables à ceux en vraie grandeur à bord d'un navire comparable, et que les forces d'impact observées restent à l'intérieur des limites de fonctionnement sûr de la tuyère.

## 16. Conclusions

Les grandes conclusions qui peuvent être tirées sont les suivantes :

1. Le système hélice-tuyère équipant l'arbre central de la maquette du Louis Saint-Laurent a donné un rendement hydrodynamique de loin supérieur à celui d'une hélice sans tuyère, lorsque les vitesses sont inférieures à 15 noeuds. Pour une même puissance, le gain de poussée au point fixe en marche avant est de 35% environ et, en marche arrière, de 70% de la poussée en marche avant.

2. Une interférence hydrodynamique importante existe entre les hélices d'extrémité et l'hélice centrale, modifiant profondément le rendement du système.

3. Avec une valeur maximale de tirant d'eau et en marche avant, la fréquence du blocage dû à l'entrée de fragments de glace de forte taille dans la tuyère centrale est très faible.

4. En marche arrière, l'ordre de grandeur des forces d'impact hélices-glaces et tuyère-glaces augmente.

5. Une réduction du tirant d'eau et de la taille des fragments entraîne une augmentation sensible de la fréquence des impacts hélices-glaces et tuyère-glaces.

6. En marche arrière, il arrive fréquemment que des fragments de glace se trouvent coincés entre la coque et les bossages des hélices d'extrémité.

7. En marche arrière, avec des hélices entraînant l'eau vers la coque, les fragments de glace sont poussés contre la coque et le

long du talon central, augmentant les risques de coincement et de blocage et aussi le nombre d'impacts.

8. Les impacts hélices-glaces résultent de l'interaction coque-glaces et non de la succion exercée par les hélices sur les fragments, surtout en marche arrière.

9. Les fragments de glaces sont assujettis au phénomène de "vitesse critique" c'est-à-dire que leur trajectoire devient instable et qu'ils ralentissent lorsque la vitesse critique est dépassée. L'action anti-blocage est plus efficace si la vitesse de marche reste au-dessous de celle-ci.

10. Les conséquences d'un blocage sont maximales lorsque, en marche avant, la tuyère se trouve bloquée dans sa partie médiane.

11. Grâce à la force qu'ils exercent, les jets d'eau sont un moyen efficace de lutte contre le blocage.

12. L'utilisation de glace-modèle en cire pour simuler un champ de glace fragmenté s'est révélé commode et fructueuse.

13. Le temps de basculement d'un fragment entravé par un mur (paroi) est de quatre fois celui d'un fragment isolé libre.

## 17. Recommandations

Les recommandations suivantes sont formulées concernant les navires devant naviguer dans les glaces :

- Protéger par une tuyère l'hélice centrale de tout brise-glace à trois hélices.

- Modifier la forme des talons d'extrémité et la direction de rotation des hélices d'extrémité à la lumière des résultats obtenus.

- Naviguer à la valeur maximale de tirant d'eau, surtout si des marches arrière fréquentes sont prévues.

- Redessiner la partie arrière du navire de manière à réduire au minimum le nombre de fragments aspirés dans le cercle balayé par les hélices, surtout en marche arrière, et porter une attention particulière à la géométrie de la coque et des appendices éventuels, tels que déflecteurs, etc.

- Redessiner l'entrée de la tuyère pour réduire au minimum les conséquences d'un engorgement de la tuyère dans sa partie médiane (les plus néfastes), grâce à des soufflages (blisters) placés à l'avant et à l'arrière de la tuyère.

- Doter la proue d'un moyen, exemple un décrochement, permettant de casser la couche de glace et aux fragments de remonter plus tôt à la surface.

- Donner aux déflecteurs une structure leur permettant de résister à de très importants efforts verticaux.

- Donner aux dispositions de déviation des glaces une forme qui tienne compte de la vitesse critique, au-delà de laquelle ils deviennent inefficaces. Une action graduelle et prolongée est plus efficace qu'une action rapide et brutale.

- Utiliser si possible des jets d'eau pour dévier les fragments de glace, surtout en marche arrière.

- Donner au système hélice-tuyère des caractéristiques hydrodynamiques le rendant peu sensible aux importantes fluctuations de la force de sillage consécutives à un blocage.

- Rendre ce système capable de résister aux forces vibratoires consécutives à un blocage.

## TRAVAUX DE R-D FUTURS

Élaborer un programme d'essais visant à évaluer l'effet des jets d'eau pour la déviation des fragments de glace, surtout dans la partie arrière du navire en prévision des marches arrière.

Étudier et évaluer des modèles de poupes considérant leur aptitude à tenir les fragments de glace loin du cercle balayé par l'hélice.

Approfondir l'interférence entre les hélices d'extrémité et l'hélice centrale dans le but de trouver une configuration optimale.

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# 1. INTRODUCTION

Nozzles offer the following advantages for icebreaking ships:

- augment thrust at low speeds by some 30%,
- protect propellers against impacts with very large ice blocks,
- decrease the risk of cavitation and subsequent loss of thrust,
- smooth up the wake nonuniformities and increase propeller efficiency,
- allow for the application of CPPs and geared transmission systems, which broadens the designer's options,
- increase astern thrust capabilities,
- other.

A main disadvantage of the nozzle is their blockage with ice, which happens particularly often in heavy ice conditions and shallow drafts. A blocked nozzle has to be flushed with water flowing in the direction opposite to that which caused the blockage in the first place. This procedure is troublesome and adversely affects the performance of the vessel.

This R&D programme is aimed at understanding the causes of ice blockage of the proposed nozzle of CGS LOUIS S.ST. LAURENT and proposing the means of blockage minimization.

## 2. PROJECT OBJECTIVES

*The MODAL OBJECTIVE of this project is to contribute to the development of all aspects of technology required to ensure the safe and efficient year round navigation capability in arctic waters of CANADIAN INTEREST.*

*The MODAL SUB-OBJECTIVE of the project is to advance the state of the art and performance capabilities of marine vessels used by government or by industry for safe and efficient year round operation in Arctic waters of CANADIAN INTEREST by fostering the development of hull, propulsion and auxiliary systems technologies for improved performance in ice.*

*PROJECT OBJECTIVES are to:*

- *EVALUATE the flow pattern of ice pieces as they may enter a nozzle and to investigate their influence on power, torque and thrust.*
- *INVESTIGATE the variations in performance of the propeller as a function of blockage of the nozzle.*
- *PROPOSE solutions to minimize the blockage problem.*

*The undertakings necessary for achieving the objectives of this project are described in the following chapters.*

## *3. WORK PLAN*

*Eight steps are necessary to be made in order to achieve the project objectives:*

*3.1.**PREPARATION OF THE DETAILED WORK PLAN**, including:*

- *the activity schedule,*
- *cash flow projection,*
- *project management control,and*
- *project documentation procedures.*

*APPENDIX A contains the details of the work plan developed in this step.*

*3.2. **CONDUCTING THE LITERATURE SEARCH,** and summarizing the available information on the propeller ice interaction and nozzle blockage. The scope and findings of the literature search are incorporated into the final report, in the APPENDIX B.*

*3.3. **DEVELOPMENT OF TEST PLAN** for ice flow and blockage investigation of the center propeller of CCGS LOUIS S. ST. LAURENT's one to fifteen (1:15) model. APPENDIX C contains details of the test plan.*

*3.4. **CONDUCTING OF THE MODEL TESTS.** The model, nozzle, and simulated ice pieces had to be prepared, instrumented and calibrated satisfactorily and in accordance with the approved test specifications.*

*The first series of tests determines the parameters influencing the flow of the submerged ice blocks:*

- *buoyancy forces,*
- *frictional properties,*
- *hydrodynamic drag.*

*The second test series determines:*

- *waterjet forces acting on a simulated ice block, as a potential ice flow control and blockage prevention device.*

*The third series determines:*

- *overload tests of the model equipped with the centerline nozzle.*

*The fourth series determines:*

- *forces on the propulsor and the nozzle during the* *controlled simulated blockage.*

*The fifth series determines:*

- *the ice flow and blockage parameters of the model moving thru pre-broken ice field,*

*APPENDIX L contains the detailed description of the testing and full documentation of the data collected.*

***3.5. ANALYSIS OF THE TEST RESULTS*** *is performed right after the completion of the tests. The analysis includes the following:*

- *Determination of the propeller suction forces acting on ice pieces.*
- *Determination of the influence of the*
  *simulated ice field characteristics and*
  *ship operational characteristics*

  *on the output parameters :*

  *flow pattern of ice pieces*
  *speed of approach*
  *frequency of blockage*
  *predominant region of blockage*
  *frequency of interaction with the propeller*

- *Development of the recommendations based upon the results of the tests as to the modifications of the ship's stern region in order to minimize the occurrence and severity of blockage.*

- *Development of the model modification design and the new test programme aimed at the confirmation of the expected benefits.*

***3.6. PREPARATION OF THE INTERIM REPORT****, covering the work done to date.*

### *3.7. CONDUCTING THE MODIFIED MODEL TEST PROGRAMME.*

*The model and its instrumentation were modified to measure the frequency and the severity of blockages and ice/ propeller interactions with modified stern/nozzle arrangement.*

*The sixth series determines:*

- *the overload characteristics of the model equipped with the blockage prevention device.*

*The seventh series determines:*

- *the ice flow and ice/propeller interaction characteristics* *of the model equipped with the ice deflector.*

***3.8. WRITING OF THE FINAL REPORT.*** *This has been accomplished by writing the report as the work progresses. The report includes the EXECUTIVE SUMMARY, a MAIN REPORT and the APPENDICES, which fully document the work performed together with the results, conclusions and recommendations.The publication standard is that of TDC.*

*The main report is written in the sequence of the tests conducted. The chapters on:*

- *the waterjet tests and*
- *thrust augmentation/wing propellers interference are, on the request of the SCIENTIFIC AUTHORITY, written as the self contained documents.*

## *4. LITERATURE SEARCH*

*Fifteen literature items were identified as relevant to the project topic. Their detailed review is contained in the Appendix C. Here, the summary of main findings is given.*

*The papers can be classified into the following categories:*

- *FULL SCALE TRIALS REPORTS (References 3,4,5,7,12),*
- *MODEL TEST DATA (References 6,11)*
- *ANALYTICAL INVESTIGATIONS (References 1,2,13)*

*The full scale trials reports on the blockages of the nozzles with ice conclude that the forces developed during the blockages are of the magnitudes comparable to those developed during the direct impact between the blades and ice. For the* ***MV Robert*** *LeMeur (CPP) the following numbers apply:*

*Maximum blade force during the blockage:* ***335 kN (89%*** *of the maximum recorded)*

*The maximum torque recorded was* ***305 kNm*** *( approximately twice the bollard hydrodynamic)*

*The maximum thrust recorded was during the blockage and its magnitude was* ***1,150 kN (4.7*** *times the hydrodynamic thrust at the bollard).*
*The maximum blade bending moment recorded was* ***310 kNm,*** *which led to the local yielding of the blade.*

*The frequency of occurrence of blockages is reported to be low, at least in the level ice conditions. Due to the prolonged nature of such blockages, often lasting for several seconds, the high magnitude vibrations of the nozzle/propeller shaftline systems take place, resulting in the fatigue and wear of the propeller and shaftline components. The magnitudes of the blockage forces are several times exceeding the magnitudes of the hydrodynamic steady state forces in bollard condition. While the level of forces developed during the blockages are high, the net nozzle/propeller thrust is near nil, leading to the slowing down of the vessel.*
*While the severity of forces during the blockages may be high, the severity of the ice/open propeller interaction is equally high, often leading to the stalling of the propellers and breakage of the blades.*

*The operations of some of the* ***shallow draft vessels*** *(supply ships and small tugs and fishing boats) report frequent clogging and blockages of the nozzles with ice, making those ships inferior in their performance to those operating without the shrouds.*

*Model test data reports on the nozzle clogging and blockages*

conclude that the simulated blockages lead to the increase of the thrust and torque of the propeller and that the nozzle thrust diminishes substantially. Large magnitude vibrations also take place reaching an order of magnitude higher levels (peak to peak) than the steady state forces.
A certain size of the ice block must be achieved in order to initiate clogging or blockage. The linear dimension must be higher than:

$$s > (\text{Duct I.D.} - \text{Hub O.D})/2$$

For the model propeller having diameter of 250mm, the following forces were recorded during the simulated blockage:
* The mean values of thrust and torque increased 220 to 250% of the mean steady hydrodynamic forces.

* The peak to peak excursions of the

| | |
|---|---|
| longitudinal blade force **increased** | 1,000% |
| torque | 130% |
| thrust | 100% |
| blade spindle torque | 3,400% |
| The shaft bending moments | 700% |

The model testing teams warn against the difficulties in the measurements and control of the blockage experiments due to the high level of vibratory forces occurring during the tests.

A quick drop of the blockage induced forces is reported when the blocking piece is distanced away from the nozzle mouth.

Analytical investigations deal with the suitability of the nozzle as a thrust augmenting and propeller protection device. As a propulsor, the nozzle offers numerous advantages and is well suited for icebreaking applications on certain types of vessels. For the nozzle of LSSL, the following parameters apply:

| | |
|---|---|
| Thrust of the system (shrouded/open) at 3kn ahead: | **1.38** |
| Bollard pull astern (shrouded/open): | **1.58** |
| Maximum speed achievable (shrouded/open): | **0.99** |
| Cavitation potential(shrouded open): | **small/large** |
| Maximum thrust/power ratio bollard ahead: | **17 kG/HP** |
| bollard astern | **14 kG/HP** |
| Average thrust/power ratio bollard ahead: | **11.4 KG/HP** |

The strengthening of the nozzle to withstand the impacts with ice can be accomplished by the increase of the scantlings of nozzle structure and/or by the thickening of the nozzle section profile. For the proposed LSSL nozzle the **design impact ice force** is:

780.0 tonnes (full scale),
**2,267.2 N** (model scale).

*A similar propeller of 4.2m diameter was installed and tested on the twin shaft, 14.1 MW research ship MV POLAR STERN. The following full scale forces were measured:*

***210 tonnes*** *astern (622N model scale)*
***120 tonnes*** *ahead*

*The frequency of interaction with the shrouded propellers of the ship was found to depend on the ice conditions and the power level.*

*The parameters identified as important in determining ice/propeller interaction frequency were:*

*bow shape*
*ship length*
*ship draft and beam*
*flatness of the bottom*
*number and configurations of the shafts,*
*propeller submergence*
*shaft power*
*ship speed and*
*ice conditions*

*The means of preventing and/or alleviating the severity of blockages identified in the literature are:*

* *ice deflecting devices (fins, deflectors, cages),*
* *water bypass devices (slots in the nozzle rings) and*
* *air injection into the propulsor/nozzle.*

*A detailed description of the effect of these measures is contained in Chapter 14.*

## 5. TEST PLAN

The following tests were developed for this programme:

Phase one

**Broken ice properties tests**

- buoyancy tests
    - float up unconstrained
    - float up constrained
    - float up from the bottom of the model
    - dragging tests

- friction tests
    - wax on paint dry/wet
    - wax on wax dry/wet

- strength tests

    - flexural strength
    - bending strength

**Propulsion performance tests with the nozzle in open water**

several speeds ahead and astern with the wing propellers working, at different power levels.

bollard tests ahead and astern with the centerline shaft power held constant and wing propeller power varying.

**Simulated blockage condition tests**

ahead and astern operations at near bollard conditions with varying geometry of the blocking piece and distance from the nozzle.

drag tests on the blocking pieces.

**Tests in simulated broken ice field**

ahead and astern, varying power levels, ship speed and ice coverage and the draft of the vessel.

**Waterjet tests**

varying water pressure, depth of submergence of the jet, nozzle geometry and distance between the orifice and the target.

*Phase two*

***Propulsion performance tests with the blockage preventive device*** *in open water*

> *ahead and astern, varying power levels and speed of the vessel.*

***Tests in simulated broken ice field with the device.***

> *ahead and astern, varying power levels, ship speed and ice coverage and the draft of the vessel.*

*The test plan evolved about the existing 1:15 scale model of CCG Louis S. St Laurent, made of fiberglass reinforced foam. The model was refurbished, reinforced and the nozzle and propeller installed in the stern aperture. A new dynamometer was brought in capable of resisting large ice /propeller interaction forces. The model has proven to be too flexible for this particular test series and caused many shaft alignment problems. Also the attachment of the appendages to the hull has proven to be very difficult, which caused breaking of the ice deflecting device and the premature termination of the second phase tests.*

*The details of the testing programme as planned are contained in APPENDIX B and the details of the tests as executed are contained in APPENDIX L.*

# *6. FLOAT-UP TESTS RESULTS*

## ***6.1 Tests setup***

*A series of ice block float-up tests was conducted in the open water basin. Schematic of the test set-up is shown in Figure 6.1.*

*Three types of tests were performed:*

*free floating,*
*wall constrained, and*
*model constrained*

*In addition, brief ice block dragging tests were performed in order to establish the onset of a critical velocity of the blocks.*

*The paraffin ice blocks were of various sizes, weights, and shapes as shown in Table 6.1. The mean density of the blocks was 866 kg/m^3.*
*All together 11 different blocks were tested.*

*The blocks were released in three different positions:*

*flat face up*
*long edge up*
*short edge up*

*In the wall constrained experiments, the ice blocks were released short side up or long side up.*

## ***6.2 Test method***

*The ice blocks were submerged to a predetermined depth, using calibrated rod and the time of emergence was measured by two stop watches. A number of measurements were done for each depth and the arithmetic mean of the emergence time established.*

## ***6.3 Test results/ free float-up***

*Table 6.2 summarizes the results of the float-up tests and Table 6.3 shows the results of the wall float-up tests.*

*Figure 6.2 shows the dependence of the emergence time on the depth of submergence for ice block #1, released flat face up. Regression performed gave the following output:*

*time of emergence (sec) = 0.624 + 5.8509 * depth (m).....6.1*

*The correlation is very strong (r^2 = 0.995).*

*The linear relationship proves that the effective speed of the emergence is, defined as*

$$V_{eff} = d(depth)/d(time)$$

*is constant for a given block and is independent of depth.*

*Figure 6.3 confirms the linear relationship between the depth and time for other blocks. Figure 6.4 shows the influence of the size of the ice blocks on the time of emergence.*

*The time of emergence of the blocks from the depth of 1.6m as a function of block weight is shown in Figure 6.5. It is evident, that the heavier the ice block, the shorter its emergence time. The relationship between the emergence and the weight is linear:*

$$\text{emergence time (sec)} = 14.8 - 1.898 * \text{weight (kg)} \quad \ldots\ldots\ldots 6.2$$

*for the depth of 1.6m. Correlation is strong ($r^2 = 0.918$)*

*Conclusions:*

* *Heavier blocks emerge faster than the light ones, regardless of the shape.*
* *The time of emergence of very small blocks is finite.*
* *The relationship is linear, within the range tested.*

*The initial orientation of the ice block influences the speed of emergence, as shown in Figure 6.6.*

*The flat face-up release leads to the slowest speed, while the long edge up is faster. The tests with the short edge up were inconclusive, due to the instability of the block. The float-up time for the edge release is not linear with the depth, due to the very pronounced non-linear motions developed.*

## 6.4 Analytical formulations of ice block emergence

*When released from a certain depth, an ice block is subject to the following external forces:*

*Weight*
*Buoyancy*
*Drag*
*Damping.*

*Drag for small Reynolds numbers* **Re** *is proportional to velocity. For the large* **Re**, *it is proportional to the velocity squared. From Figures 6.2, 6.3, 6.4 it is clear that most of the depth is travelled at a constant velocity, which, on the average is 0.2m/s. This gives the Reynolds number as:*

$$Re = 0.2 * 0.25/(1.18 * 10^{-6}) = 4 * 10^{4}$$

*This number places the drag coefficient in a supercritical range where it is speed independent. This gives the drag forces as proportional to the velocity squared.*

*Damping is a complex function of the velocity. However, for the purpose of this analysis we will approximate the damping component as also dependent on the square of the velocity. This assumption will be tested by comparing the results of the analysis with the experiments.*

*The equation of motion in the time domain can be written as:*

$$(1+la)*m*z'' + 1/2*row*Ao*cr*z'^{2} = D - W \quad \ldots\ldots\ldots\ldots\ldots\ldots 6.3$$

*where:*

**m** *is the mass of ice block, in kg,*
**la** *is the added mass coefficient,*
**z** *is the vertical distance travelled by the ice block, positive up;*
**row** *is the mass density of water, (roi is the density of ice),*
**cr** *is the combined drag and damping coefficient,*
**Ao** *is the head surface area of an ice block,*
**D** *is the displacement of ice block, in Newtons,*
**W** *is the weight of ice block, in Newtons.*

*The solution of this equation is:*

$$z(t) = mr/B * \ln(coh((A*B)^{0.5}*t/mr)) \quad \ldots\ldots\ldots\ldots\ldots\ldots 6.4$$

*where mr is the reduced mass:*

$$mr = (1+la) * m,$$

$$A = D - W,$$

$$B = 1/2 * row * cr * Ao.$$

The float-up velocity can be expressed as:

$$V = Vcr * \tanh ((A*B)^{0.5}/mr*t) \ldots\ldots\ldots 6.5$$

Critical velocity Vcr is:

$$Vcr = (2*g*Hi*(row/roi-1)/cr)^{0.5} \ldots\ldots\ldots 6.6$$

where $g$ is the gravity acceleration and, $Hi$ is the thickness of ice block.

A simplified function of $z(t)$ can be expressed as:

$$z(t)simpl = mr/(2*B) + Vmax * t \ldots\ldots\ldots 6.7$$

An inspection of the solutions reveals that:

After an initial short acceleration of a block, the long distance is travelled at nearly constant velocity Vcr, which is the maximum velocity the block can attain.
The limiting velocity depends on the:

thickness of ice,
density ratio of water and ice and
drag coefficient cr.

**The density ratio is the most influential parameter.**

**Limiting velocity does not depend on the area of the ice block or** added mass coefficient.

Figure 6.7 shows the velocity function for block #1.

Figures 6.8, 6.9, 6.10, 6.11 show the results of computations of float-up time/distance function for the blocks #1, 3, 5 and 7; respectively. **Excellent agreement with the data is achieved** by tuning the drag and added mass coefficients. The drag coefficient controls the critical speed (near end of emergence), while the added mass coefficient controls the initial acceleration (near zero time).
Such an agreement with experimental data justifies the assumptions made.

*Table 6.4 summarizes the data obtained by curve fitting:*

*TABLE 6.4*

*SUMMARY OF FLOAT-UP PARAMETERS*
*OBTAINED FROM ANALYTICAL FORMULATIONS*

| Ice block | drag coeff<br>cr<br>- | added mass coeff<br>la<br>- | Thickness<br>Hi<br>m | velocity<br>Vcr<br>m/s |
|---|---|---|---|---|
| 1 | 3.3 | 5 | 0.037 | .168 |
| 3 | 0.5 | 4 | 0.054 | .360 |
| 5 | 0.7 | 2 | 0.048 | .261 |
| 7 | 9.0 | 4 | 0.011 | .008 |

*Notable points:*

***The effective drag coefficient decreases strongly with an*** *increase in thickness.*

***The added mass coefficient varies, but averages approx 4.*** *These trends are shown in Figure 6.12.*

*It should be emphasized that the upward motion of the ice blocks, especially smaller ones, was not a straight line. Oscillations about the vertical axis or spiral motions were common. This makes the computed drag and added mass coefficients the effective (mean) values, not the instantaneous ones.*

## *6.5 Test results: wall float-up tests*

*The test parameters are summarized in the Table 6.3.*

*Figure 6.13 shows that the time of the float-up from the vertical position adjacent to the wall to the flat, free floating position is approximately*

> ***4 times greater than*** *the time needed to achieve this position with the piece away from the wall.*

*This is because of two factors:*

> *wall restraining the free movement, and*
>
> *water suction into the space between the wall and the block.*

*Further, while the free float-up time decreased with the* *increase of the weight of the ice block (as in the previous tests), the reverse tendency was observed near the wall.*

*The rectangular pieces set in water with the narrow edge up rotated first to the wide edge up position and then rotated away from the wall.*

*Some pieces turned away from the wall upper edge first, while others the lower edge first.*
*In either case, the pieces were pushing on the wall substantially before floating away to the equilibrium position.*

### *6.6 Test results: model bottom release*

*The influence of the weight on the float-up time of the ice piece submerged to the bottom at the bow of the ship (station 1.5), is shown in Figure 6.14. Again,the heavier blocks emerge sooner. The correlation is very similar to that observed in the free floating tests.*

*The tests were carried out at three locations:*

*bow*
*midbody*
*stern*

*The float-up times, from the ship's bottom, were:*

*bow: 1.75 sec*
*midbody: 2.25 sec*
*stern: 2.00 sec*
*--------------------*
*MEAN: 2.00 sec*

*For a model of LWL(length at the water line) of 7.355m, travelling at different speeds, the calculated point of emergence of an unconstrained block from a full submergence at 0.21L aft of FPP is:*

| *vship knots* | *v model m/s* | *calculated emergence point, aft of FPP, % LWL* |
|---|---|---|
| *0* | *0* | *21.0* |
| *5* | *0.664* | *39.0* |
| *10* | *1.238* | *54.6* |
| *15* | *1.992* | *75.2* |

### *6.7 Dragging tests*

*These pilot tests were performed outside of the scope of this project to confirm the presence of a "critical speed" of the ice*

*blocks, at which the motions become unstable.
An ice block, free floating at the surface was, pulled by a wire "harness" with the dynamometer attached to the end.*

*Table 6.5 shows the accelerating force applied, time needed to travel the distance of 2 meters and the overall speed.
Figure 6.15 shows the relationship graphically.*

*An important observation resulted:*

> ***speed of travel is INVERSELY proportional to the force*** *applied.*

*At high initial accelerations, a high initial velocity would result in the dynamic instability of the piece and consequently large diving motions, which would delay the arrival of the piece at the end of the 2m track.*

*The average pulling force leading to the motion instability was:*

*3.5 kG,*

*which is less than the weight of 4.5 kg of the piece.
The speed at which the instability occurred, was*

*0.23 m/s*

### *6.8 CONCLUSIONS FROM FLOAT-UP TESTS*

1. *Emergence time is proportional to the depth.*
2. *Emerging ice blocks attain quickly the limiting speed of ascent which is a constant for the block.*
3. *The critical (limiting ) speed is dependent on:*

   *ice block thickness,*
   *ratio of ice density to water density*
   *drag coefficient.*
4. *Free ice float-up motion can be well represented by the analytical formulation given in the text.*
5. *Motions of ice blocks are oscillatory, but stable.*
6. *Heavier ice blocks emerge faster than the light ones.*
7. *Edge-up emergence is faster than the flat face up.*
8. *Distance travelled by an emerging ice block can be approximated by a formula:*

   $$z(t) = a + V_{cr} * t$$

   *where **a** is a constant particular to the specifics of an ice* block, and **Vcr** is the limiting velocity.

9. Effective added mass coefficients of ice blocks are approx 4.

10. Effective drag coefficients of ice blocks decrease with an increase of ice block thickness.

11. Float-up time of an ice block near the wall is approximately 4 times longer than the free float-up time.

12. Float-up times of ice blocks released from the bottom of the model decrease with an increase of block's weight.

13. For the block tested, average float-up time from the bottom of the ship was 2 sec. The longest time was at the midbody position.

14. For suddenly accelerated ice blocks, the average speed of travel was inversely proportional to an initial acceleration.

15. There exists a critical speed, beyond which an ice block's free motion becomes unstable and overall speed slows down.

16. In order to attain large distances when pushing ice blocks away, gentle accelerations below the critical speed are needed, not sudden large magnitude impulses.

### 6.9 Miscellaneous observations:

Free float-up tests

* In general, the initial motions of blocks were stable at the beginning, until a certain critical speed of emergence was achieved. Then, the motions became oscillatory, in a vertical plane, very much similar to those of falling leaves.

* The motions were very sensitive to the initial condition of release. Even a slight tilt away from the horizontal plane would result in large variations of the path and time of ascent.

* The leaf-like oscillations of the ice blocks were limited in the horizontal extent. In some cases they were dampened at the final phase of ascent to near zero.

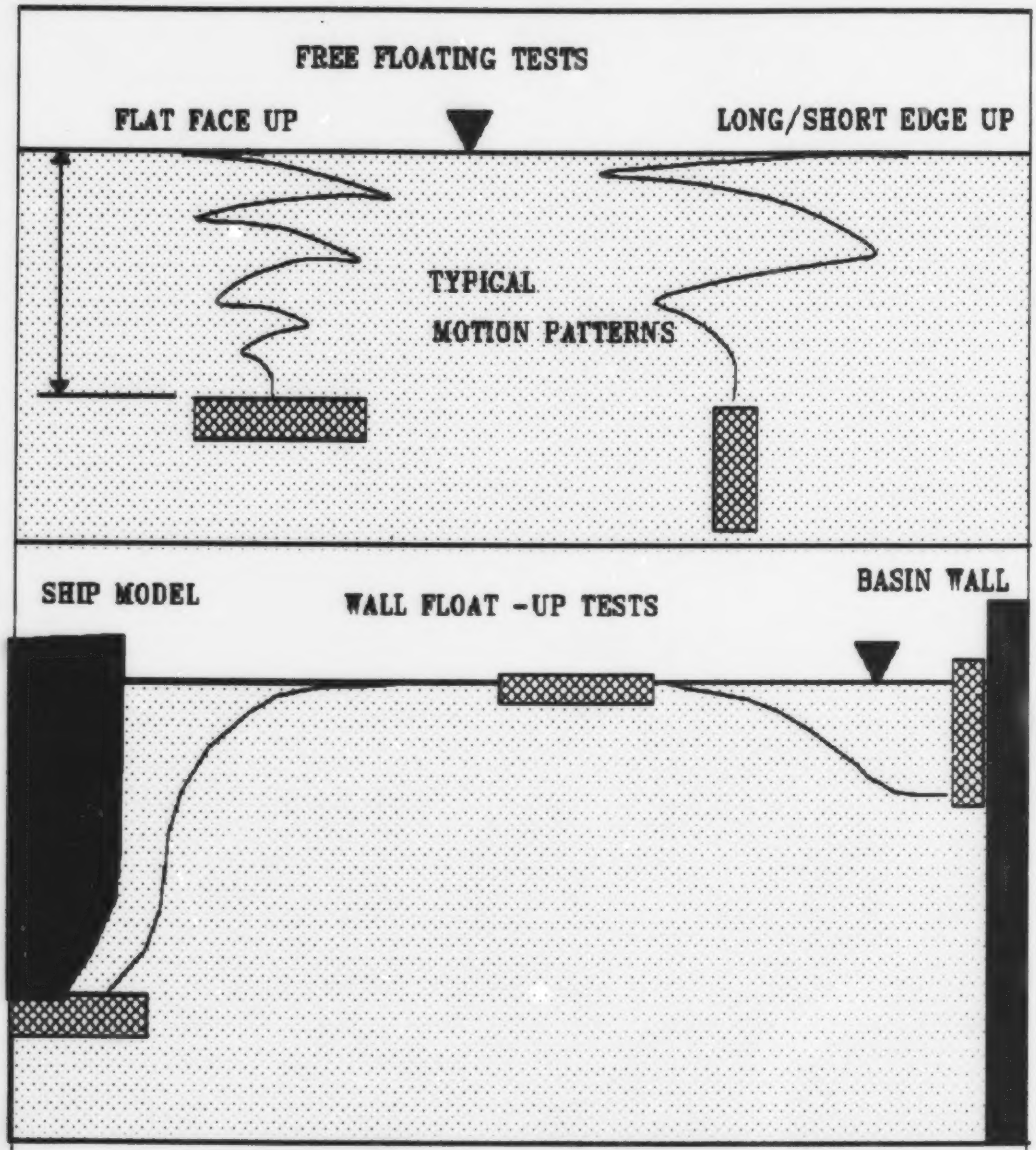
* In many cases a strong horizontal motion at the free surface resulted from the leaf-like oscillations.

* Small ice blocks showed more pronounced oscillations in a vertical plane.

* In contrast to this type of oscillation, some pieces began to

*rotate (spiral motions) upwards.*

- *The resulting motions were a function of the depth of submergence.*
- *When surfacing, all pieces contained large amounts of kinetic energy.*



| | | | |
|---|---|---|---|
| FIGURE TITLE: SCHEMATIC OF THE FLOAT-UP TESTS | | | |
| PROJECT NAME: ICE FLOW AND BLOCKAGE | | | PROJECT NR: |
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: 6.1 |

## TABLE 6.1

## ICE BLOCK GEOMETRY

| BLOCK NUMBER | LENGTH MM | WIDTH MM | THICK' MM | WEIGHT KG | VOLUME M^3 | ROI* KG/M^3 | SHAPE |
|---|---|---|---|---|---|---|---|
| 1 | 450 | 200 | 37 | 2.9 | 0.00333 | 871 | BLOCK |
| 2 | 346 | 252 | 37 | 2.8 | 0.00323 | 868 | BLOCK |
| 2-1 | 345 | 253 | 39 | 2.7 | 0.00340 | 793 | BLOCK |
| 3 | 297 | 299 | 54 | 4.5 | 0.00480 | 938 | BLOCK |
| 4 | 453 | 181 | 56 | 4.3 | 0.00459 | 936 | BLOCK |
| 5 | 350 | 251 | 48 | 4 | 0.00422 | 949 | BLOCK |
| 6 | 297 | 293 | 35 | 2.9 | 0.00305 | 952 | BLOCK |
| 6-1 | 301 | 302 | 34 | 2.9 | 0.00309 | 938 | BLOCK |
| 7 | 178 | 172 | 11 | 0.252 | 0.00034 | 748 | OCTAGONAL |
| 8 | 131 | 125 | 13 | 0.177 | 0.00021 | 831 | OCTAGONAL |
| 9 | 86 | 88 | 11 | 0.069 | 0.00008 | 829 | OCTAGONAL |
|  |  |  |  |  | MIN | 748 |  |
|  |  |  |  |  | MAX | 952 |  |
|  |  |  |  |  | AVG | 866 |  |
|  |  |  |  |  | STD | 80.5 |  |

* DENOTES ICE MASS DENSITY

## TABLE 6.2

## SUMMARY OF FLOAT-UP TIMES

TIME, IN SECONDS

| DEPTH, METERS | #1 | #2 | #3 | #4 | #5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 1.15 |  |  |  |  |  | 0.90 |  | 1.11 | 0.80 | 1.18 |  |  |  |
| 0.20 | 1.81 | 2.29 |  | 1.68 |  | 2.33 | 1.43 |  | 1.52 | 1.28 | 1.47 | 2.64 | 1.77 | 1.17 |
| 0.30 | 2.11 |  | 3.70 |  |  |  | 1.77 |  |  |  |  |  |  |  |
| 0.40 | 3.15 | 1.52 |  | 2.77 |  |  | 1.92 |  | 2.60 | 2.24 | 3.04 | 5.17 | 3.90 | 2.91 |
| 0.50 | 3.63 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.60 | 4.13 | 1.69 |  | 4.19 |  |  | 2.92 |  | 3.36 | 2.95 | 4.23 | 7.24 | 5.79 | 4.08 |
| 0.70 | 4.71 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.80 | 5.36 | 2.21 |  | 5.42 |  |  | 3.41 |  | 4.36 | 3.78 | 5.25 | 10.34 | 7.52 | 7.63 |
| 0.90 | 5.89 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1.00 | 6.30 | 2.60 |  | 6.08 |  |  | 4.15 |  | 5.39 | 4.50 | 6.46 | 13.40 | 10.54 | 8.16 |
| 1.10 | 7.36 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1.20 | 7.41 | 5.12 |  | 6.74 |  |  | 5.03 |  | 6.25 | 5.29 | 7.27 | 15.70 | 11.60 | 10.73 |
| 1.30 | 8.55 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1.40 | 8.50 | 5.86 |  | 8.21 |  |  | 5.79 | 5.74 | 7.29 | 6.19 | 8.29 |  | 13.37 | 12.53 |
| 1.50 | 9.62 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1.60 | 9.74 |  |  | 8.74 |  |  | 6.15 | 5.89 | 7.97 | 6.63 | 9.63 |  | 15.89 | 13.32 |
| weight | 2.90 |  |  | 2.80 |  |  | 4.50 | 4.30 | 4.30 | 4.00 | 2.90 |  | 0.18 | 0.07 |

TABLE 6.3

WALL FLOAT-UP TESTS

| PIECE # | AGAINST | THE | WALL | FREE | FLOATING |
|---|---|---|---|---|---|
| | BOTTOM | TOP 1-ST | TURNING | SHORT SD | LONG SD |
| 1 | | 7.14 | | 2.84 | |
| | | 2.90 | | 2.55 | |
| | | 2.79 | | 2.60 | |
| | | 3.07 | | 2.33 | |
| AVERAGE | | 3.97 | | 2.58 | |
| 2 | | 9.45 | | | 3.33 |
| | | 10.83 | | | 3.07 |
| | | 10.96 | | | 4.02 |
| | | 9.86 | | | 3.15 |
| AVERAGE | | 10.28 | | | 3.39 |
| 3 | 5.65 | | | | 2.31 |
| | 5.77 | | | | 1.63 |
| | 12.40 | | | | 2.22 |
| | 13.81 | | | | 2.30 |
| AVERAGE | 9.41 | | | | 2.12 |
| 4 | 4.42 | 12.65 | | | 2.04 |
| | 4.51 | 12.32 | | | 2.19 |
| | 4.52 | | | | 3.18 |
| | | | | | 2.45 |
| AVERAGE | 4.48 | 12.48 | | | 2.46 |
| 5 | 15.58 | | 8.91 | | |
| | 7.28 | | 9.83 | | |
| | 7.83 | | | | |
| AVERAGE | 7.67 | | 4.69 | | |
| 6 | 10.88 | | | | 4.00 |
| | 15.78 | | | | 3.95 |
| | 13.31 | | | | 3.57 |
| | 17.14 | | | | 5.29 |
| | ? | | | | 4.02 |
| AVERAGE | 14.28 | | | | 4.20 |

Figure 6.2

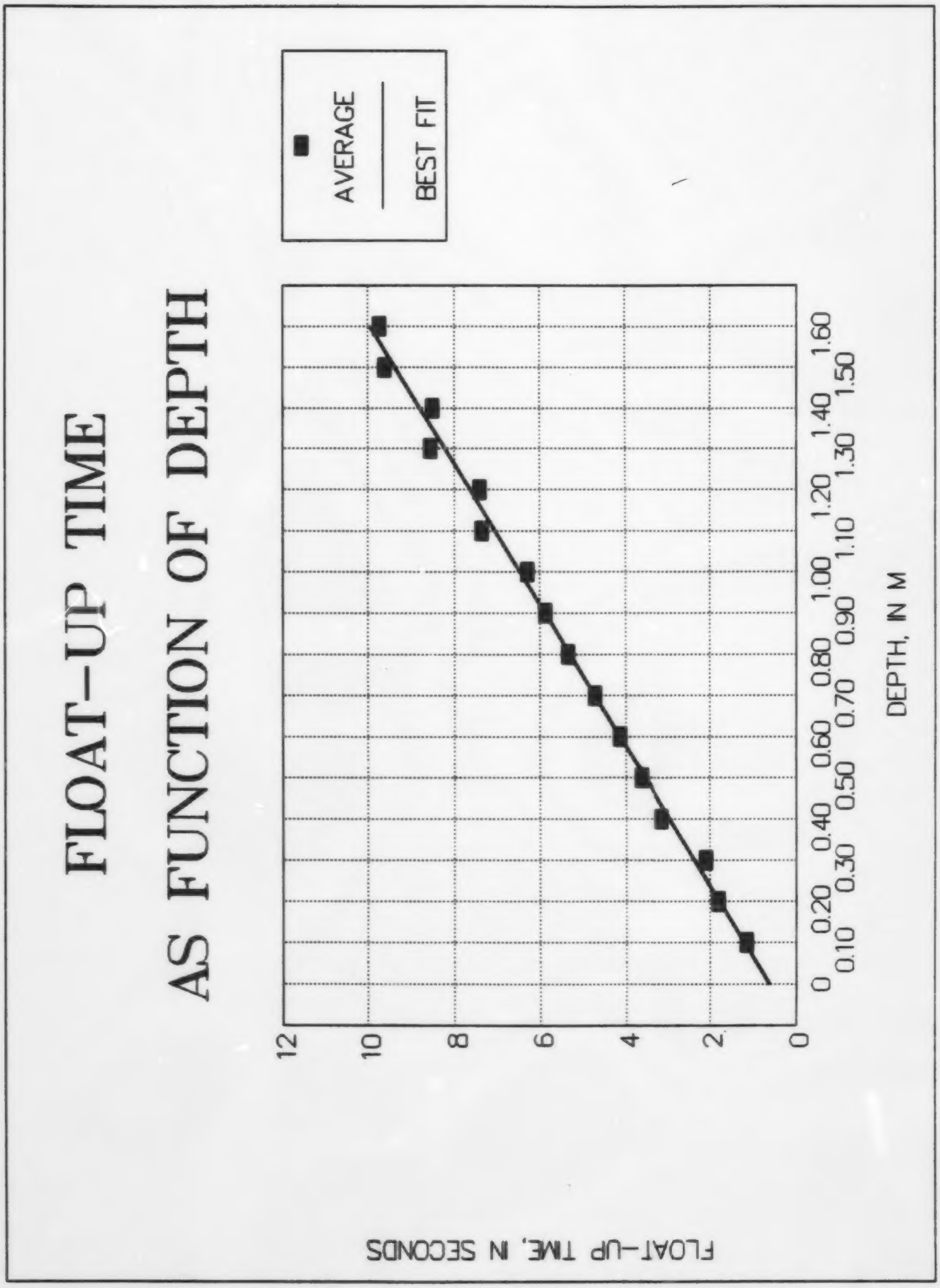

FLOAT-UP TIME
AS FUNCTION OF DEPTH
AVERAGE
BEST FIT
FLOAT-UP TIME, IN SECONDS
0
2
4
6
8
10
12
DEPTH, IN M
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60

Figure 6.3

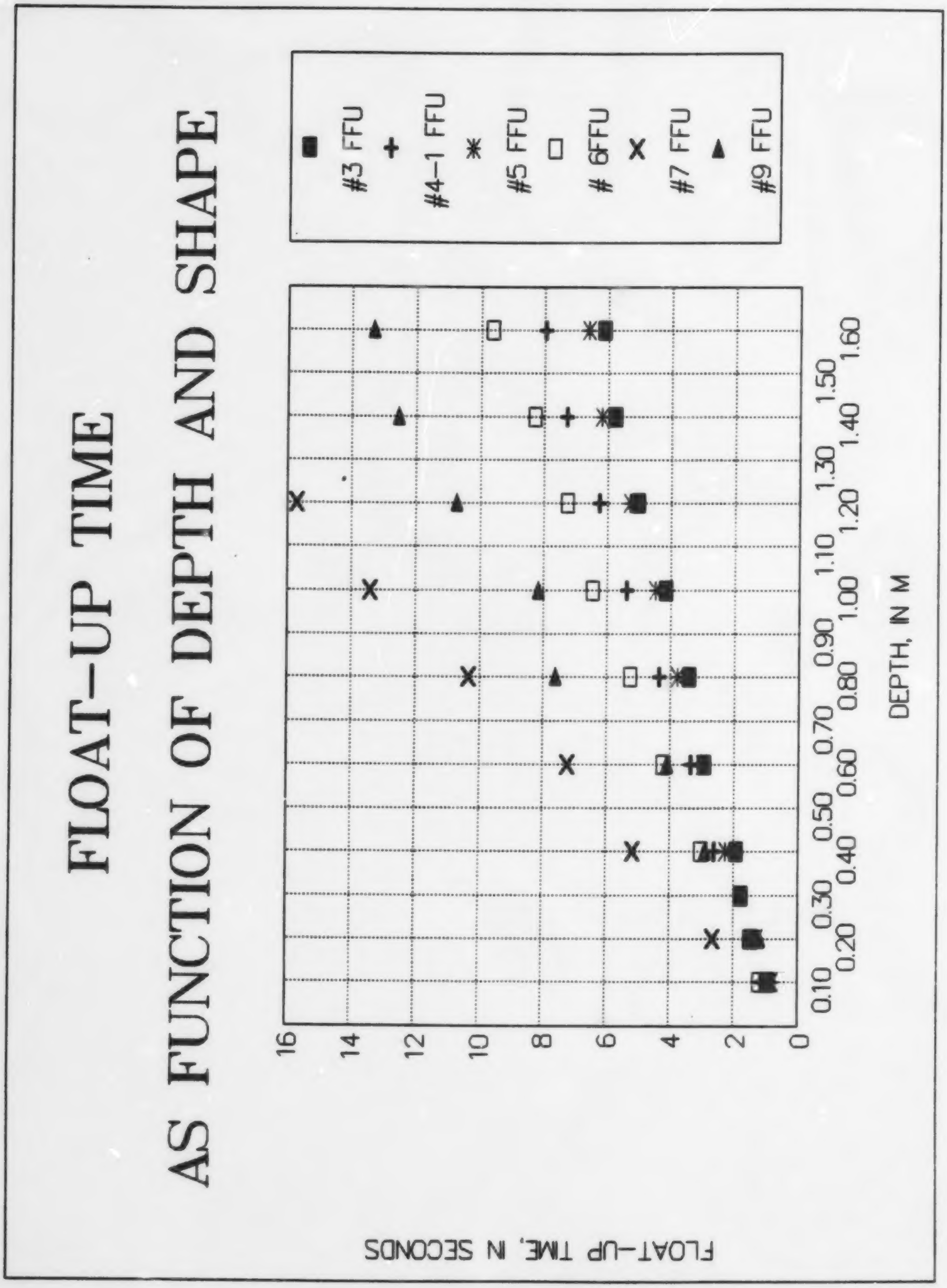
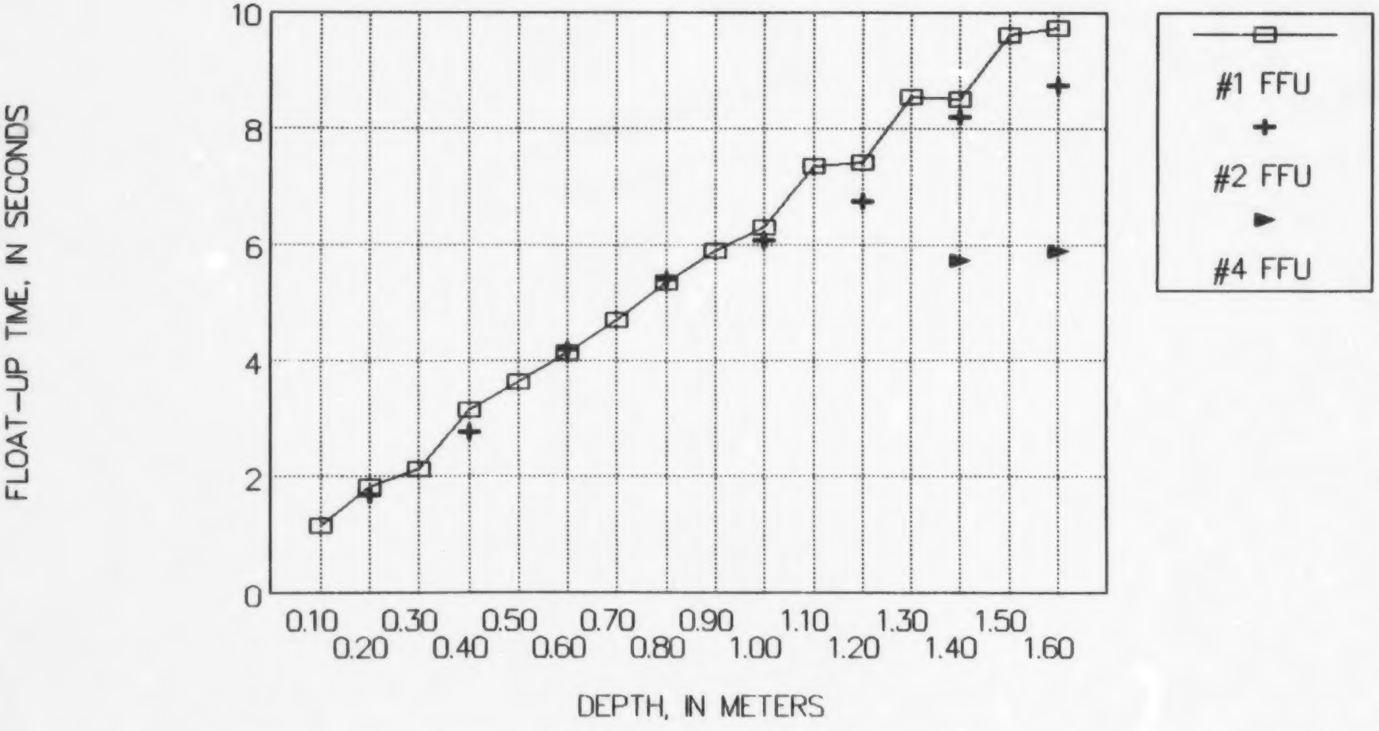
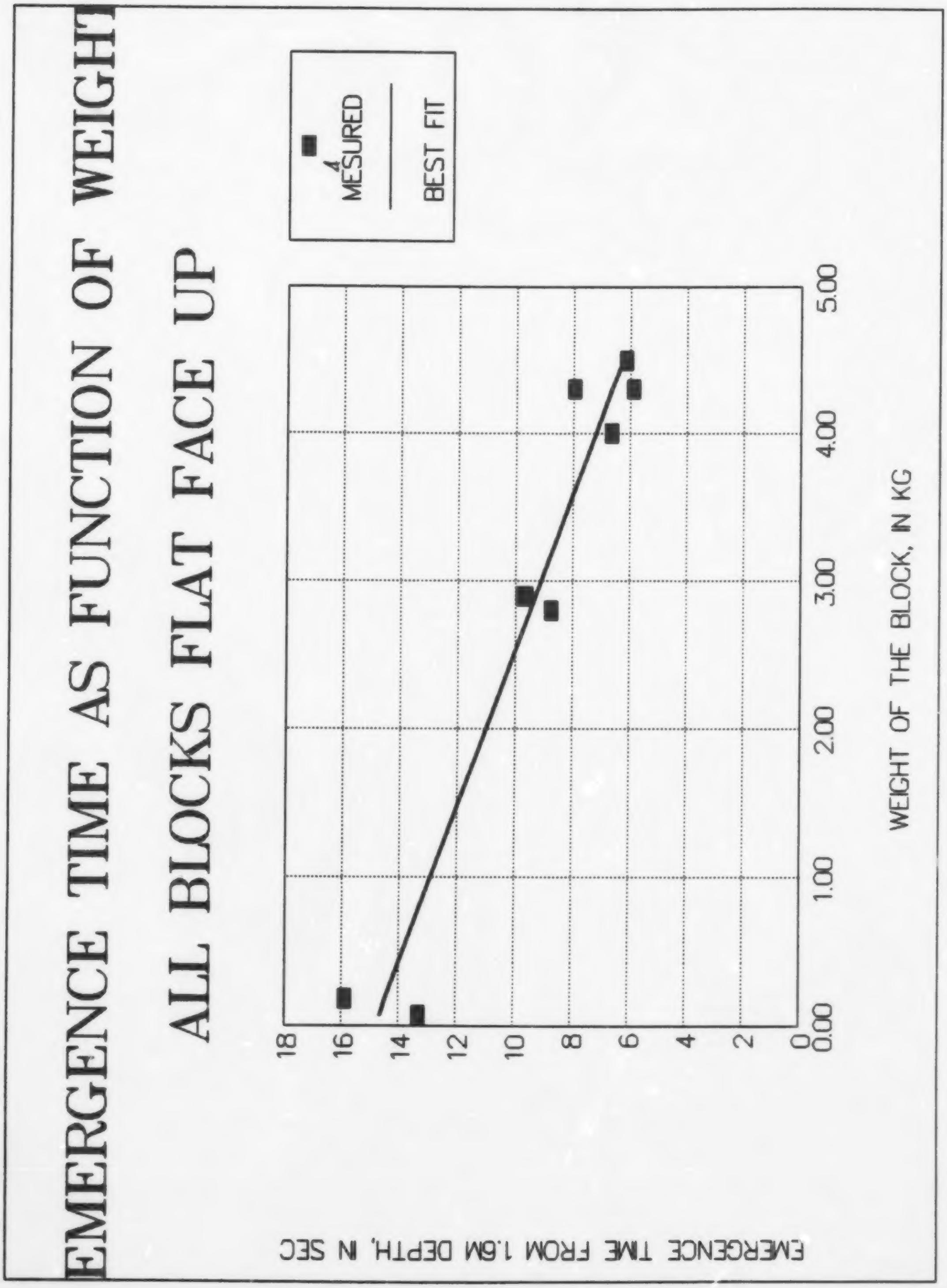

FLOAT-UP TIME
AS FUNCTION OF DEPTH AND SHAPE
#3 FFU
#4-1 FFU
#5 FFU
# 6FFU
#7 FFU
#9 FFU
FLOAT-UP TIME, IN SECONDS
DEPTH, IN M
0
2
4
6
8
10
12
14
16
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60

Figure 6.4

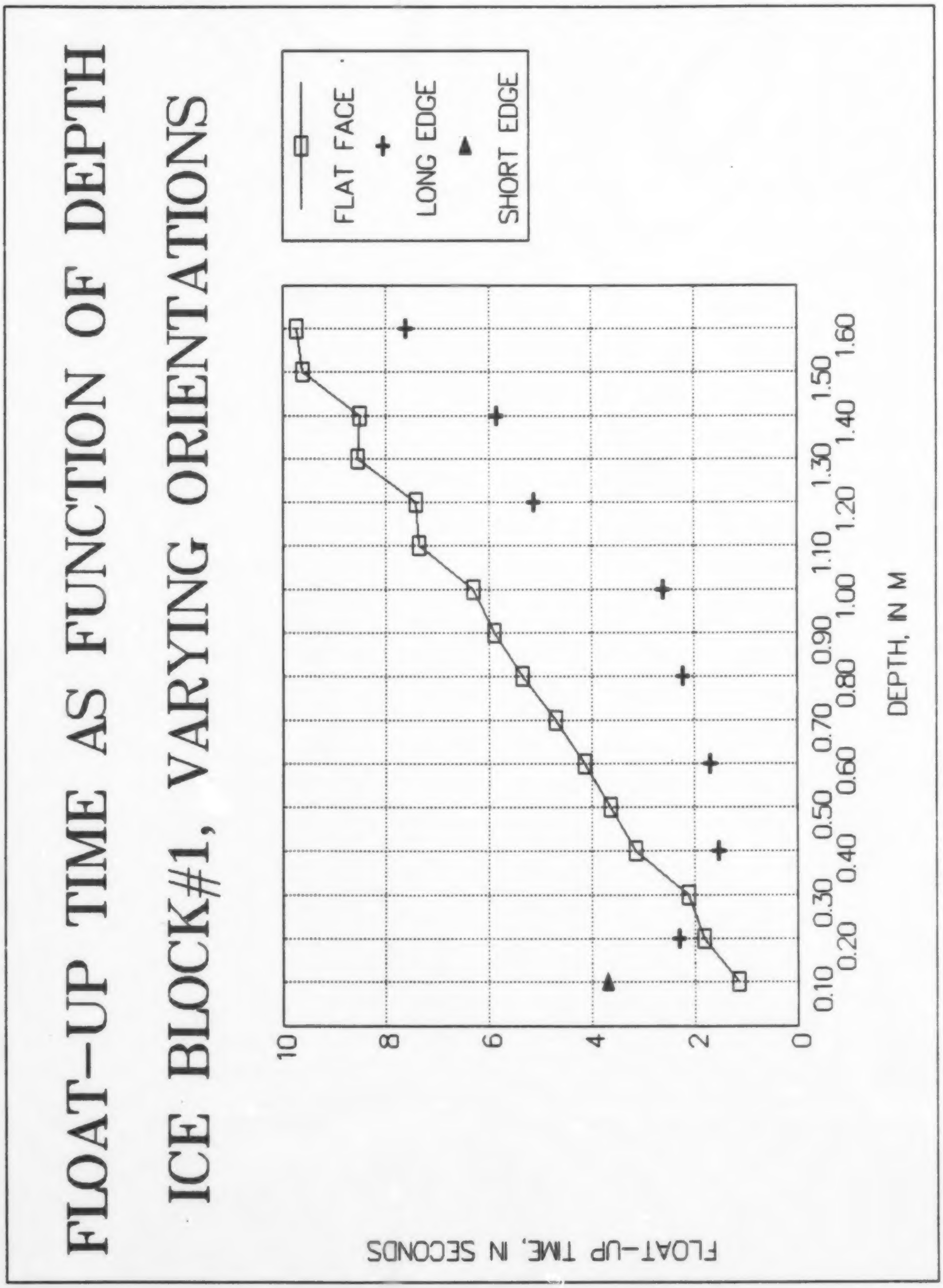


FLOAT-UP TIME AS FUNCTION OF DEPTH AND SIZE OF ICE BLOCK

Figure 6.5


EMERGENCE TIME AS FUNCTION OF WEIGHT

ALL BLOCKS FLAT FACE UP



FLOAT-UP TIME AS FUNCTION OF DEPTH
ICE BLOCK#1, VARYING ORIENTATIONS

## CALCULATIONS OF FLOAT-UP TIMES FOR DIFFERENT ICE BLOCKS

$m := 2.9 \quad row := 1000 \quad roi := 880 \quad cr := 3.5 \quad W := 2.9$

$$A := 9.81 \cdot W \left[ \frac{row}{roi} - 1 \right] \qquad Ao := 0.45 \cdot .2$$

$$B := \frac{1}{2} \cdot cr\ Ao\ row \qquad Vmax := \left[ \frac{A}{B} \right]^{0.5}$$

$ma := (1 + la) \cdot m \qquad z := 0,.01\ ..2 \qquad t := 0,0.1\ ..2$

$$V(t) := Vmax \cdot \tanh\left[ \frac{(A \cdot B)^{0.5}}{ma} \cdot t \right] \qquad Vmax = 0.157 \cdot 1$$

$$V(z) := Vmax \left[ 1 - \exp\left[ -2 \cdot \frac{B}{ma} \cdot z \right] \right]^{0.5} \qquad la := 1$$

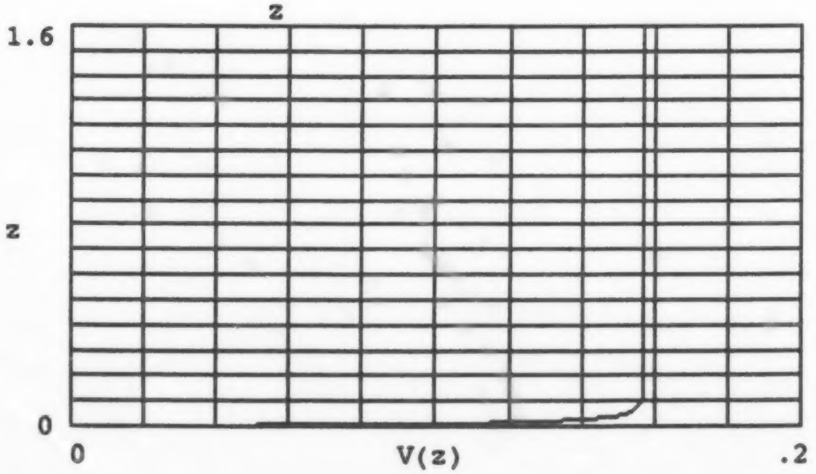


**FIGURE TITLE:**

**PROJECT NAME:** **PROJECT NR:**

**DRAWN BY:** **CHK'D BY:** **SCALE:** **FIGURE NR:** 6.7

Figure 6.8

FLOAT-UP TIME AS GIVEN BY THEORETICAL FORMULA, BLOCK#1

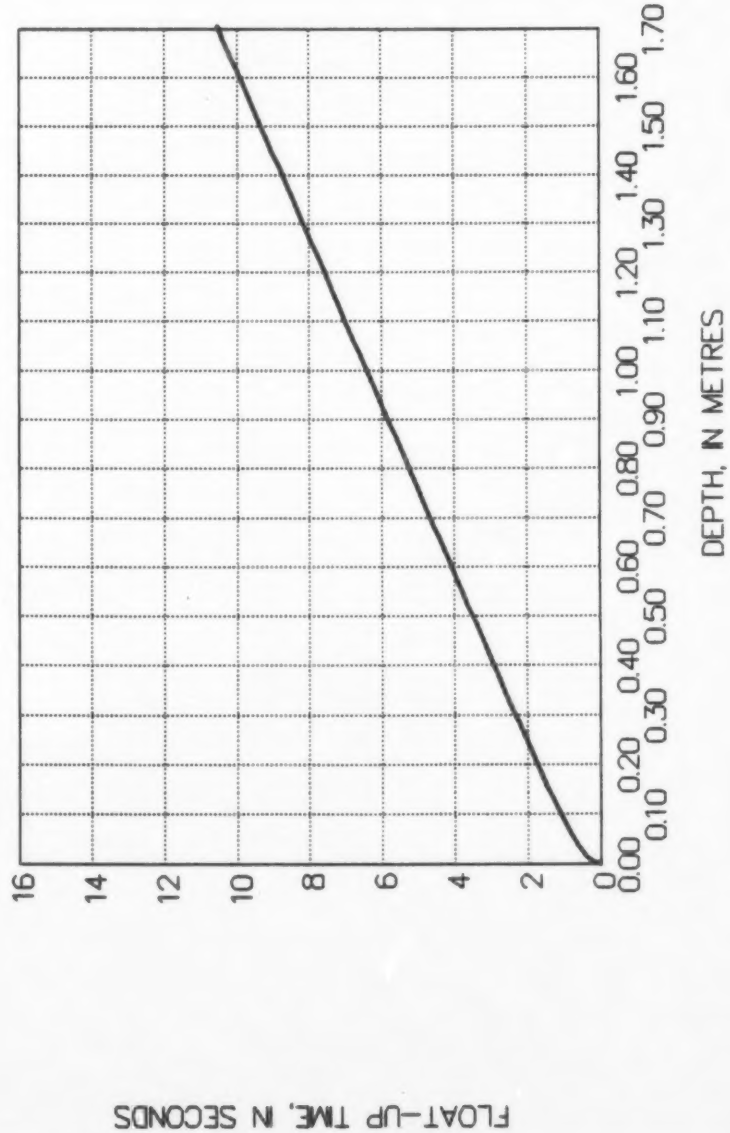


Figure 6.9

FLOAT–UP TIME AS GIVEN BY
THEORETICAL FORMULA, BLOCK#3

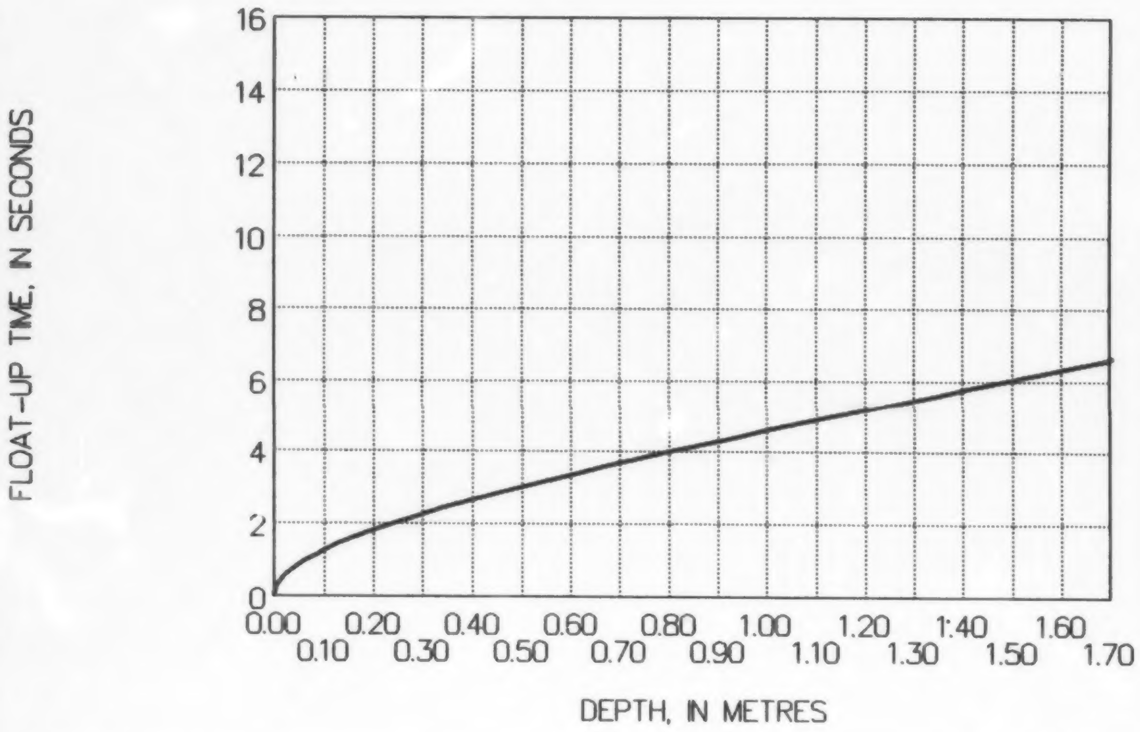
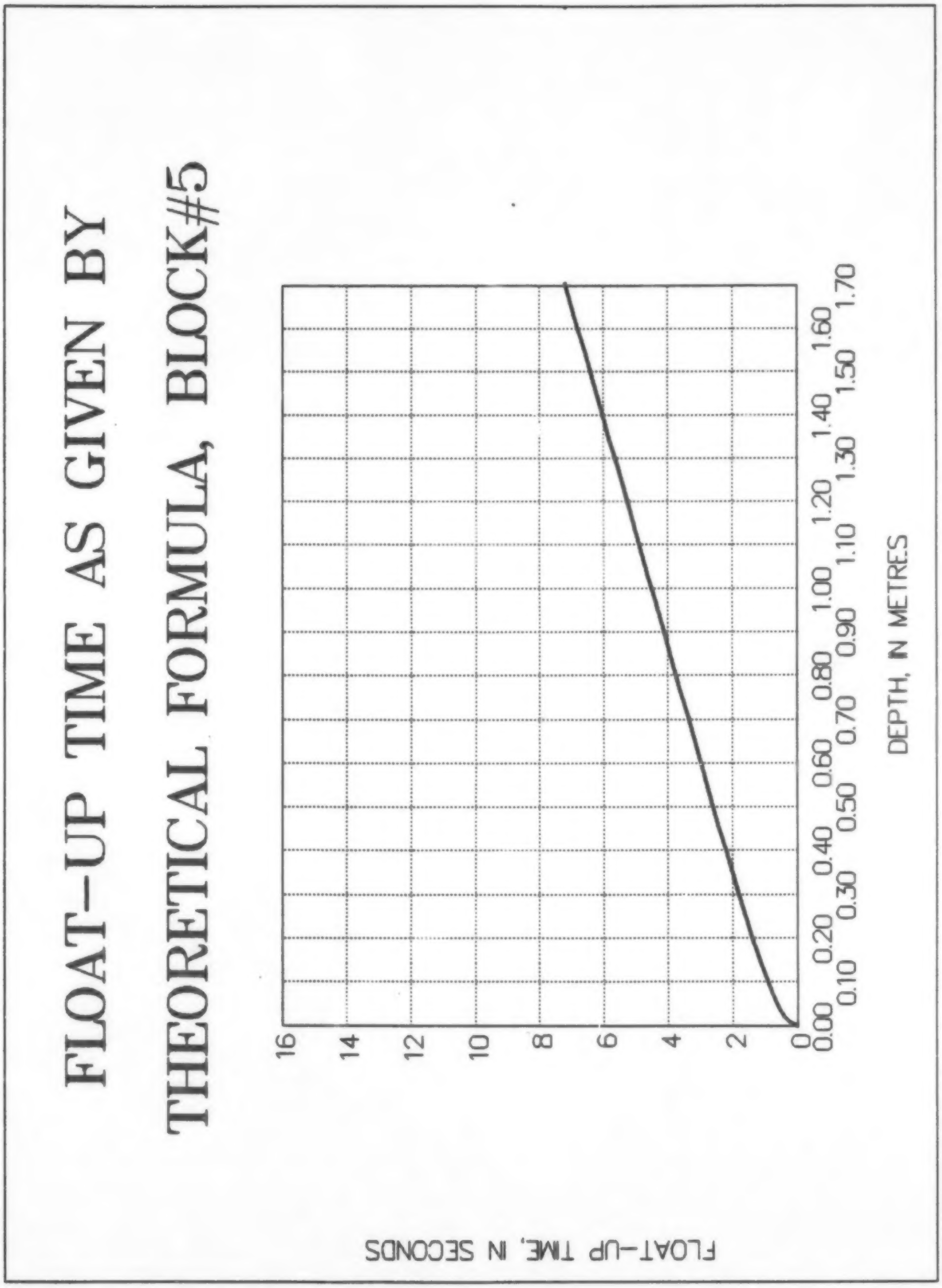
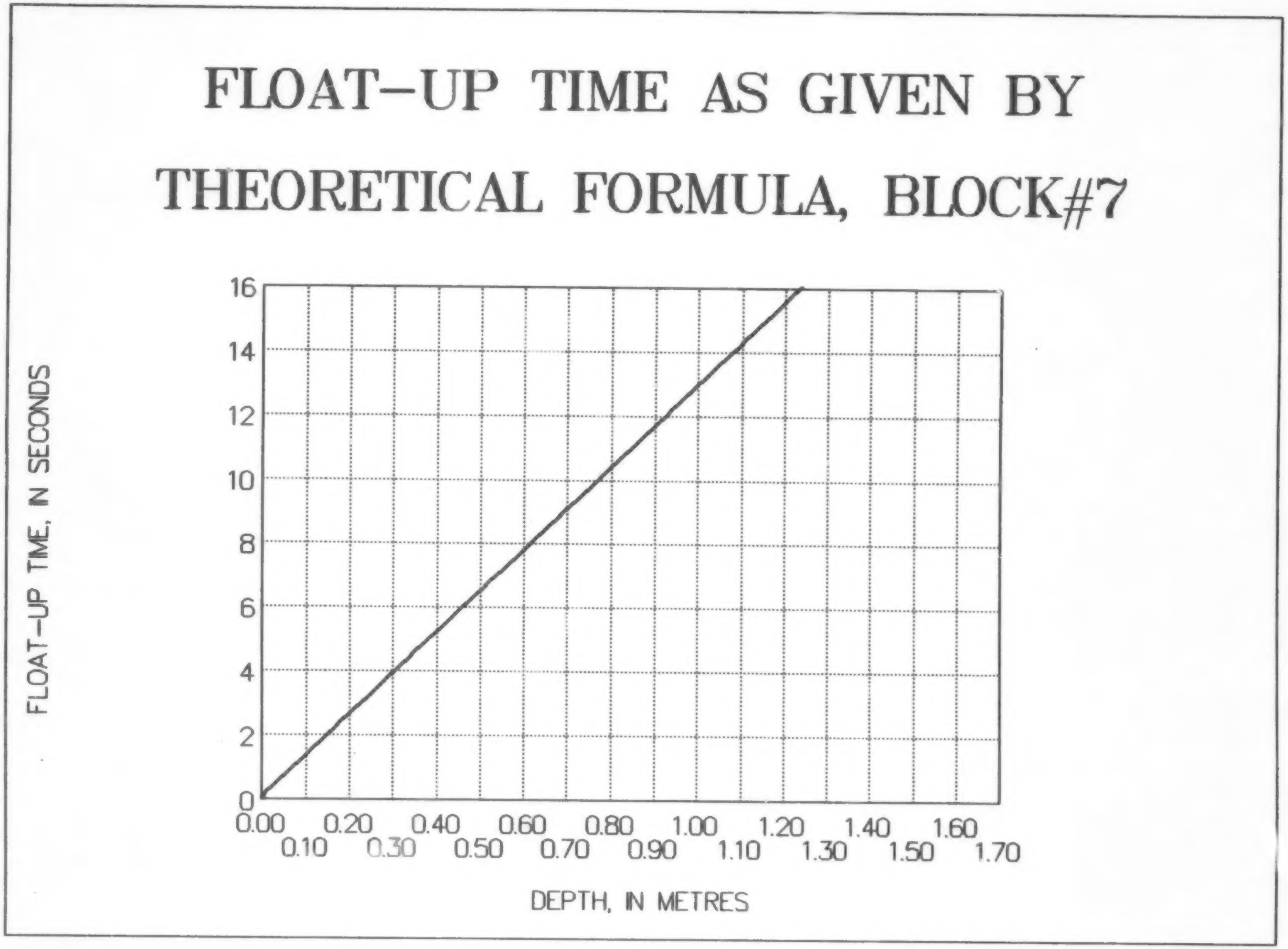


Figure 6.10



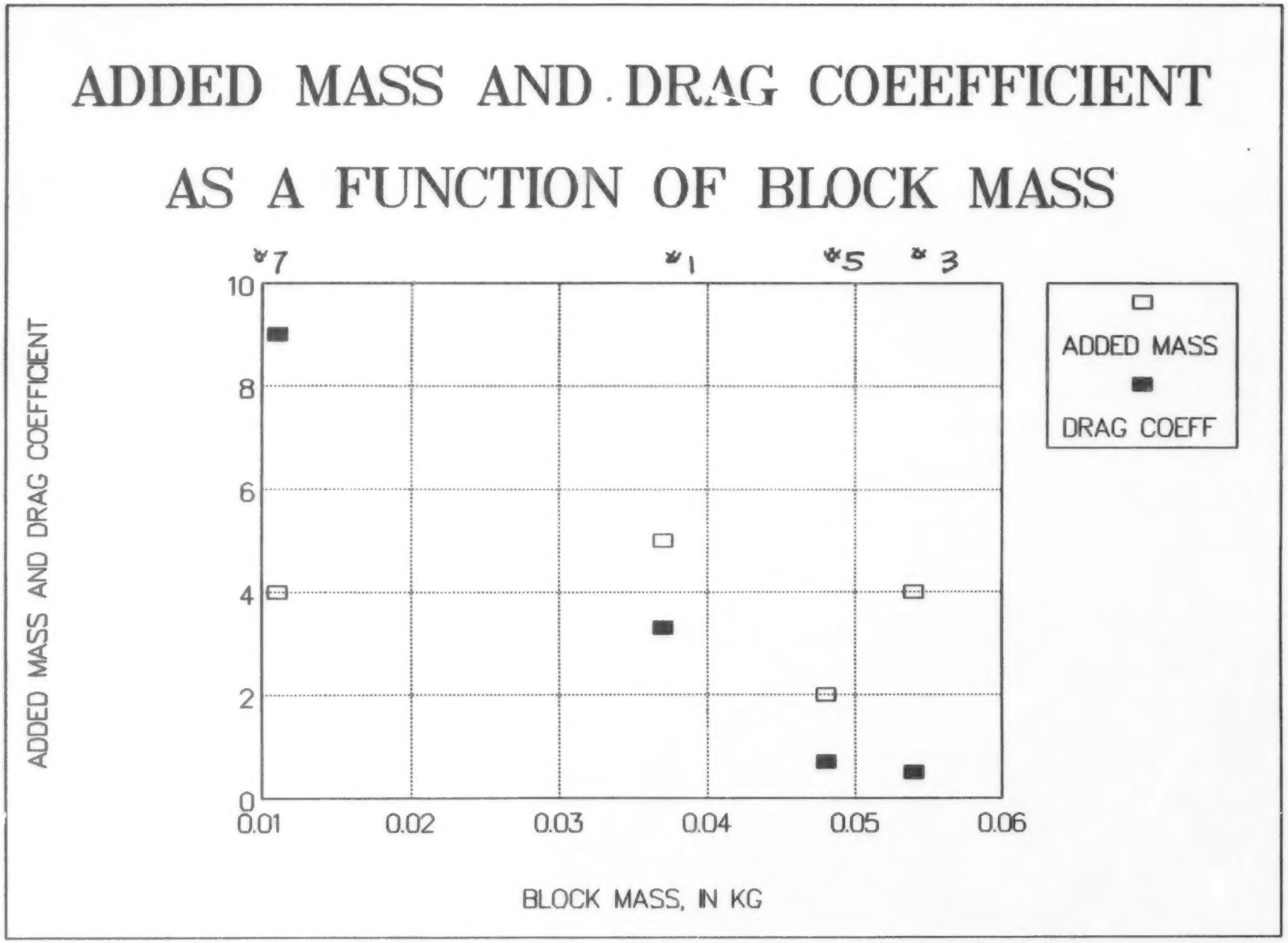
FLOAT-UP TIME AS GIVEN BY THEORETICAL FORMULA, BLOCK#5

Figure 6.11



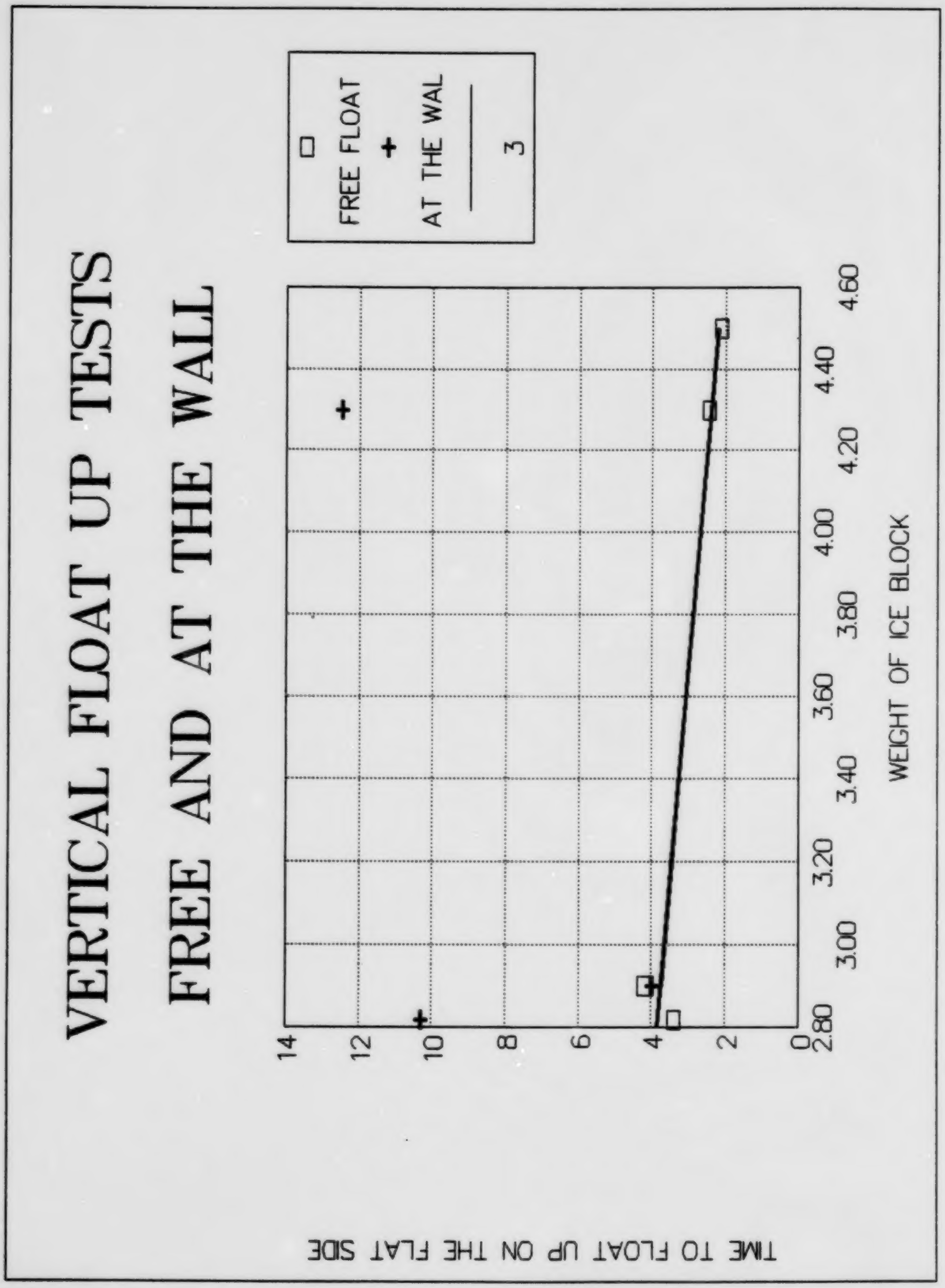
FLOAT-UP TIME AS GIVEN BY THEORETICAL FORMULA, BLOCK#7

Figure 6.12

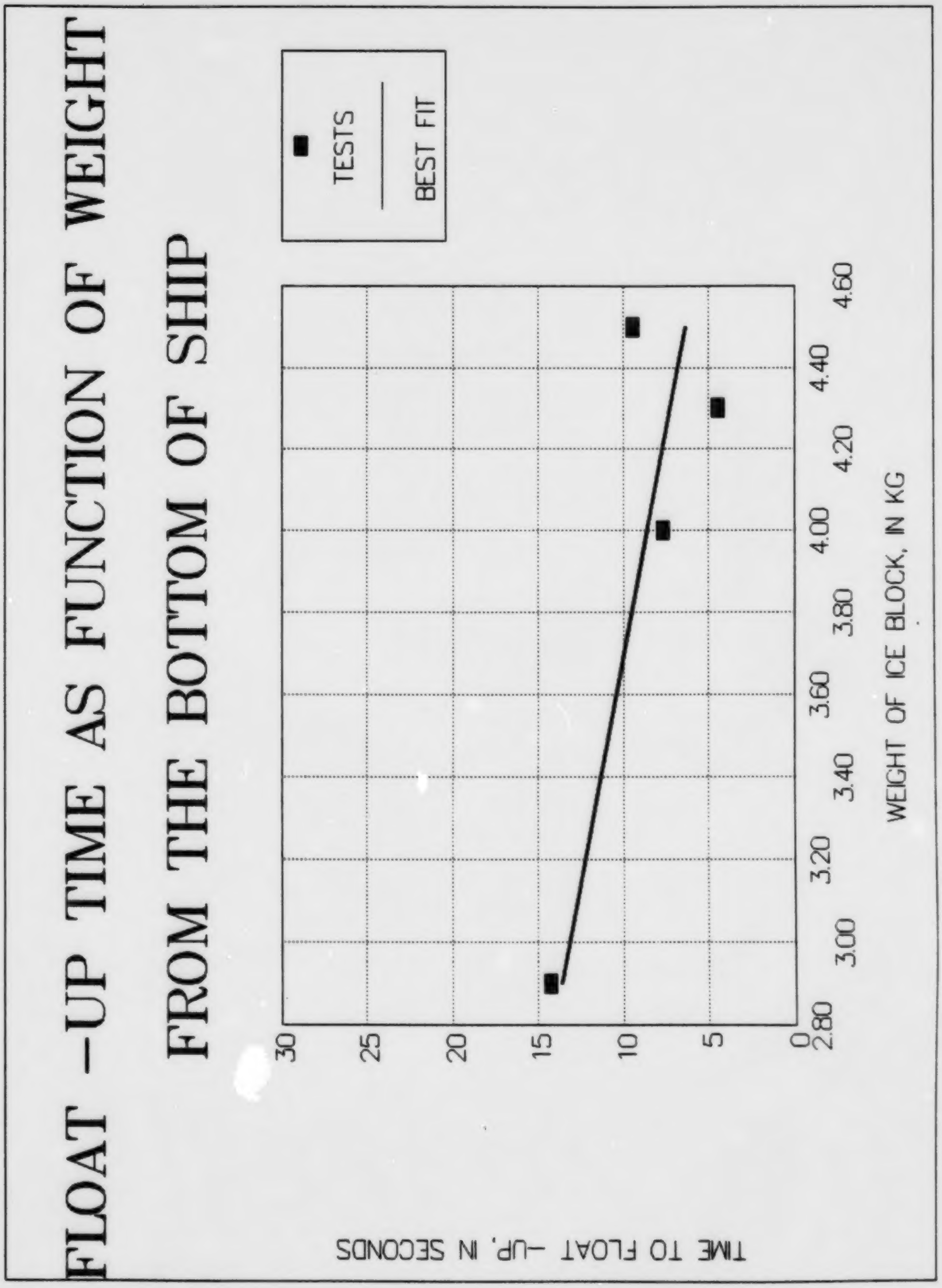


ADDED MASS AND DRAG COEEFFICIENT AS A FUNCTION OF BLOCK MASS

Figure 6.13


VERTICAL FLOAT UP TESTS
FREE AND AT THE WALL
□ FREE FLOAT
✚ AT THE WAL
3
TIME TO FLOAT UP ON THE FLAT SIDE
WEIGHT OF ICE BLOCK
0
2
4
6
8
10
12
14
2.80
3.00
3.20
3.40
3.60
3.80
4.00
4.20
4.40
4.60

Figue 6.14

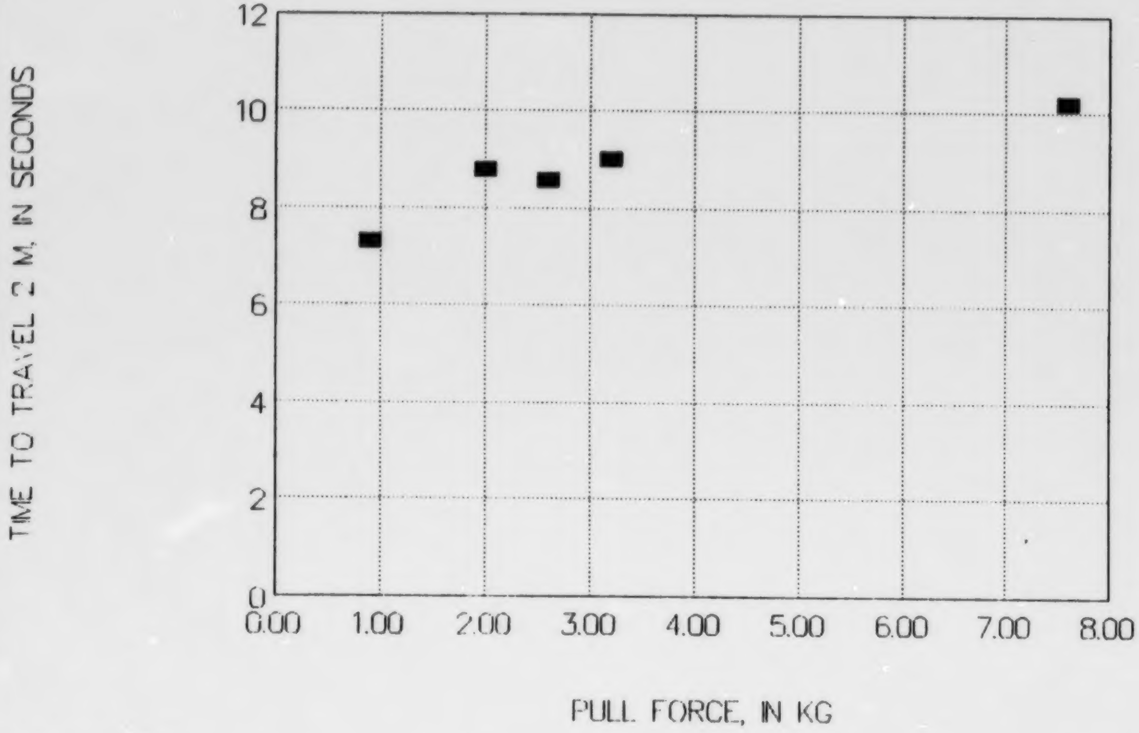


FLOAT -UP TIME AS FUNCTION OF WEIGHT FROM THE BOTTOM OF SHIP

TABLE 6.5
BLOCK DRAGGING TESTS

| FORCE KG | TIME SEC | SPEED M/S |
|---|---|---|
| 7.6 | 10.21 | 0.20 |
| 3.2 | 9.02 | 0.22 |
| 2.6 | 8.58 | 0.23 |
| 0.9 | 7.33 | 0.27 |
| 2 | 8.8 | 0.23 |

Figure 6.15



TIME TO TRAVEL 2M AS A FUNTION OF INITIAL PULL

## *7. FRICTION TESTS RESULTS*

### *7.1 Tests setup*

*For the purpose of determining the friction factor of wax blocks on wax and paint, the following apparatus was set up, as shown in Figure 7.1:*

*A plank was fabricated having one surface covered with the paint identical to that of the model*
*A second plank was covered with the melted wax surface.*

*An ice block was placed on the plank together with a digital inclinometer. The setup was either dry (above the surface) or wet (under the surface). Fifty-one (51) data points were gathered.*

*The variables were:*

*surface coating (wax/paint)*
*surface condition (wet/dry)*
*ice block weight (from 0.177kg to 4.5 kg)*
*angle of inclination*

### *7.2 Method used*

*The plank was slowly inclined to the horizontal until a slow steady motion of the ice block resulted. At that point, the inclination angle was read. The readings were repeated several times, until the repeatability of the results were obtained. The friction factor was obtained using the following formula:*

*mu = tan (inclination angle)................7.1*

### *7.3 Results*

*Table 7.1 contains the results of 51 friction experiments. The mean value of all of the experiments was*

*mu = 0.26*

*with a standard deviation of 0.05.*

*This value compares very well with the latest full scale friction experiments on the low pressure panels of an icebreaking ship coated with Inerta 160 (Rreference 7.1). The friction factor is too high for the high pressure panels, however; since the experiments dealt with prebroken ice, this discrepancy is not relevant. It is the low pressure interaction between hull and ice*

*blocks that decides on the underwater flow of ice.*
*The mean values of the friction factor for different surfaces and conditions are:*

| | |
|---|---|
| *dry wax/wax* | *0.21* |
| *wet wax/paint* | *0.24* |
| *wet wax/wax* | *0.28* |

*The influence of the block size and weight on the friction factor is illustrated in Figures 7.2, 7.3 and 7.4.*
*Only the wet wax on wax condition shows a trend indicating that the friction factor decreases with the increase of the weight. However, correlation is weak.*

### ***7.4 Conclusions:***

* *Wax blocks used have frictional properties very compatible with the full scale low pressure measurements on ice/INERTA 160.*

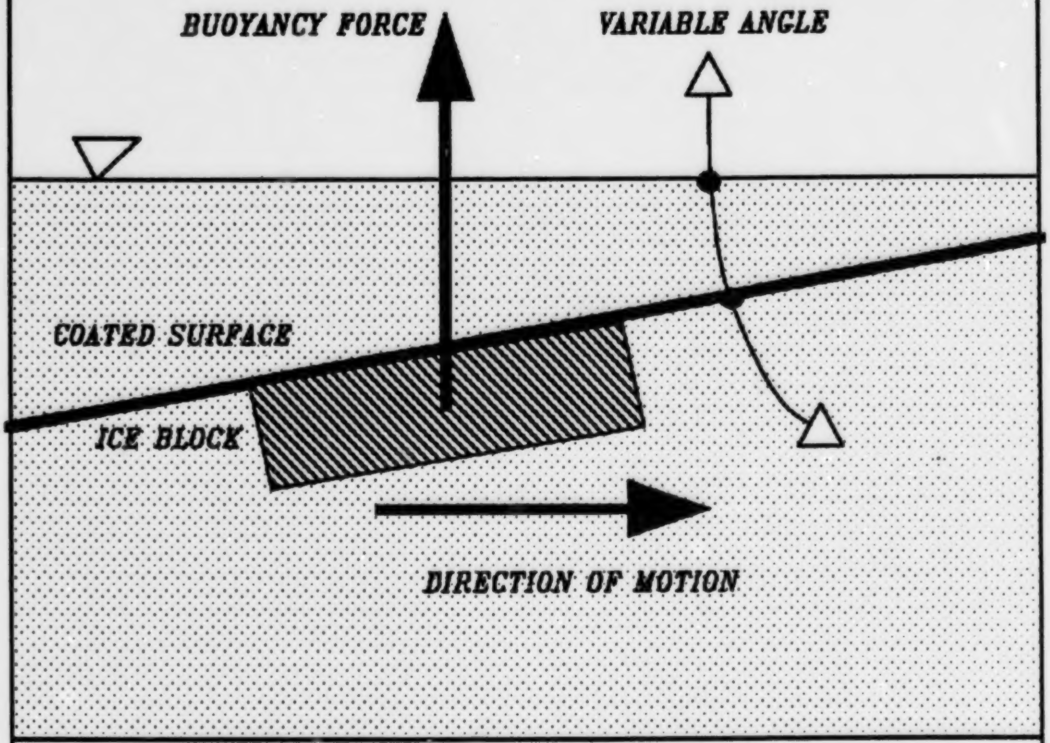
* *Method of measurements used, which reflects the actual physics of interaction between the submerged ice blocks and the hull are convenient and give consistent results.*

* *Friction factor of wax/ hull surface is 0.24, and varies slightly with the surface finish and condition.*

* *Friction factor wax/hull is not dependent on the weight of the ice blocks. A slight decrease of the friction factor was observed only for a wet wax on wax condition, which simulates the friction between the blocks.*

* *Water presence increases the friction factor from 0.21 to 0.28 for wax/wax condition.*

* *Friction between wax and hull is smaller than the friction between the blocks (0.24 versus 0.28).*



**VARIABLES:**

**SIZE OF THE ICE BLOCK**

**INCLINATION OF THE SURFACE**

**SURFACE COATING**

| | | | |
|---|---|---|---|
| **FIGURE TITLE: FRICTION TEST SETUP** | | | |
| **PROJECT NAME: BLOCKAGE INVESTIGATIONS** | | | **PROJECT NR:** |
| **DRAWN BY: VL** | **CHK'D BY: VL** | **SCALE: NONE** | **FIGURE NR:** 7.1 |

## TABLE 7.1
## SUMMARY OF FRICTION TESTS

| TEST NR | BLOCK NR | TEST CONDITION | SURFACE COAT | ANGLE OF STEADY MOTION DEGREES | FRICTION FACTOR | BLOCK WEIGTH KG | MEAN VALUE FOR COND'N |
|---|---|---|---|---|---|---|---|
| 1 | 6 | DRY | WAX | 13.80 | 0.246 | 2.900 | |
| 2 | 3 | DRY | WAX | 14.00 | 0.249 | 4.500 | |
| 3 | 2.1 | DRY | WAX | 12.10 | 0.214 | 2.700 | |
| 4 | 4.1 | DRY | WAX | 7.00 | 0.123 | 4.300 | |
| 5 | 7 | DRY | WAX | 9.90 | 0.175 | 0.252 | |
| 6 | 8 | DRY | WAX | 12.20 | 0.216 | 0.177 | |
| 7 | 1 | DRY | WAX | 14.00 | 0.249 | 2.900 | 0.21 |
| 8 | 4 | WET | PAINT | 12.85 | 0.228 | 4.300 | |
| 9 | 4 | WET | PAINT | 11.15 | 0.197 | 4.300 | |
| 11 | 4 | WET | PAINT | 12.40 | 0.220 | 4.300 | |
| 12 | 3 | WET | PAINT | 12.25 | 0.217 | 4.500 | |
| 13 | 3 | WET | PAINT | 12.60 | 0.224 | 4.500 | |
| 14 | 3 | WET | PAINT | 14.70 | 0.262 | 4.500 | |
| 15 | 3 | WET | PAINT | 12.80 | 0.227 | 4.500 | |
| 16 | 2.1 | WET | PAINT | 12.35 | 0.219 | 2.700 | |
| 17 | 2.1 | WET | PAINT | 13.72 | 0.244 | 2.700 | |
| 18 | 2.1 | WET | PAINT | 12.30 | 0.218 | 2.700 | |
| 19 | 2.1 | WET | PAINT | 11.90 | 0.211 | 2.700 | |
| 20 | 6.1 | WET | PAINT | 14.48 | 0.258 | 2.900 | |
| 21 | 6.1 | WET | PAINT | 13.90 | 0.247 | 2.900 | |
| 22 | 6.1 | WET | PAINT | 14.10 | 0.251 | 2.900 | |
| 23 | 6.1 | WET | PAINT | 12.22 | 0.217 | 2.900 | |
| 24 | 1 | WET | PAINT | 15.00 | 0.268 | 2.900 | |
| 25 | 1 | WET | PAINT | 16.30 | 0.292 | 2.900 | |
| 26 | 1 | WET | PAINT | 13.95 | 0.248 | 2.900 | |
| 27 | 1 | WET | PAINT | 15.00 | 0.268 | 2.900 | 0.24 |
| 28 | 1 | WET | WAX | 11.28 | 0.199 | 2.900 | |
| 29 | 1 | WET | WAX | 17.30 | 0.311 | 2.900 | |
| 30 | 1 | WET | WAX | 18.00 | 0.325 | 2.900 | |
| 31 | 1 | WET | WAX | 18.50 | 0.335 | 2.900 | |
| 32 | 2 | WET | WAX | 16.90 | 0.304 | 2.900 | |
| 33 | 2 | WET | WAX | 15.40 | 0.275 | 2.800 | |
| 34 | 2 | WET | WAX | 15.00 | 0.268 | 2.800 | |
| 35 | 2 | WET | WAX | 13.90 | 0.247 | 2.800 | |
| 36 | 3 | WET | WAX | 14.20 | 0.253 | 4.500 | |
| 37 | 3 | WET | WAX | 14.30 | 0.255 | 4.500 | |
| 38 | 3 | WET | WAX | 13.20 | 0.235 | 4.500 | |
| 39 | 3 | WET | WAX | 13.50 | 0.240 | 4.500 | |
| 40 | 4 | WET | WAX | 13.20 | 0.235 | 4.300 | |
| 41 | 4 | WET | WAX | 13.00 | 0.231 | 4.300 | |
| 42 | 4 | WET | WAX | 14.60 | 0.260 | 4.300 | |
| 43 | 4 | WET | WAX | 14.60 | 0.260 | 4.300 | |
| 44 | 5 | WET | WAX | 14.70 | 0.262 | 4.000 | |
| 45 | 5 | WET | WAX | 17.60 | 0.317 | 4.000 | |
| 46 | 5 | WET | WAX | 16.60 | 0.298 | 4.000 | |
| 47 | 5 | WET | WAX | 18.00 | 0.325 | 4.000 | |
| 48 | 6 | WET | WAX | 17.60 | 0.317 | 2.900 | |
| 49 | 6 | WET | WAX | 18.30 | 0.331 | 2.900 | |

```
  50      6     WET       WAX      19.40       0.352     2.900
  51      6     WET       WAX      18.80       0.340     2.900             0.28
=========================================================================
            MEAN OF ALL TESTS    14.30        0.26
            STANDARD DEV'TION     2.44        0.05

=========================================================================

REGRESSION DRY/WAX
      Regression Output:
Constant                 0.2078
Std Err of Y Est         0.0515
R Squared                0.0013
No. of Observations      7.0000
Degrees of Freedom       5.0000

X Coefficien 0.0010
Std Err of C 0.0121

==================================

REGRESSION WET/PAINT
      Regression Output:
Constant                    0.27
Std Err of Y Est            0.02
R Squared                   0.11
No. of Observations        19.00
Degrees of Freedom         17.00

X Coefficien-0.01042
Std Err of C    0.01

==================================

REGRESSION WET/WAX
      Regression Output:
Constant                 0.38512
Std Err of Y Est         0.03765
R Squared                0.24384
No. of Observations           24
Degrees of Freedom            22

X Coefficien-0.02877
Std Err of C    0.01

=========================================================================
```

FRICTION FACTOR AS A FUNCTION OF BLOCK WEIGHT, WET PAINT SURFACE

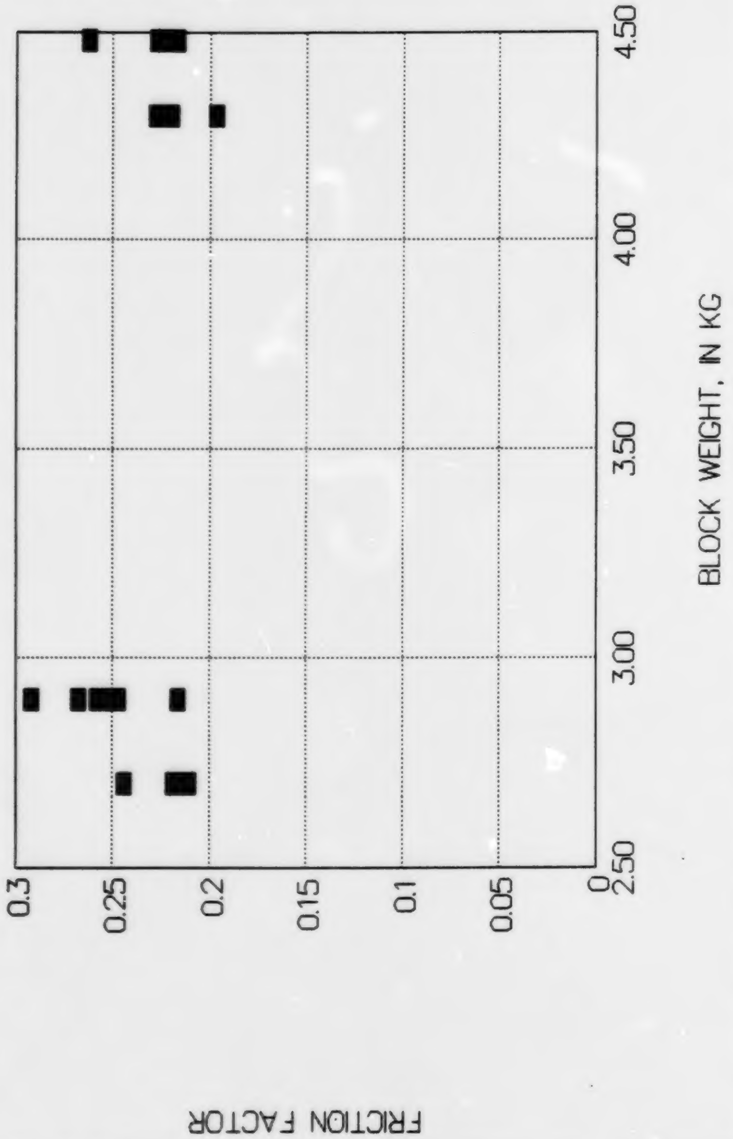


Figure 7.3

FRICTION FACTOR AS A FUNCTION OF BLOCK WEIGHT, DRY WAX SURFACE

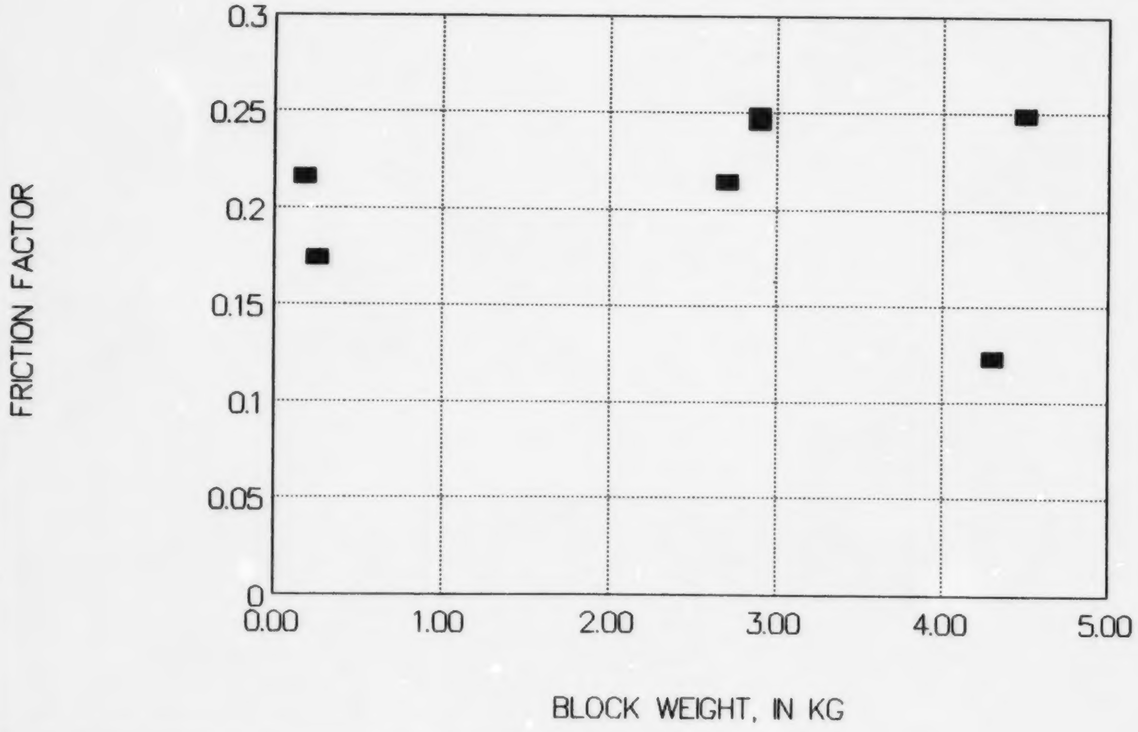
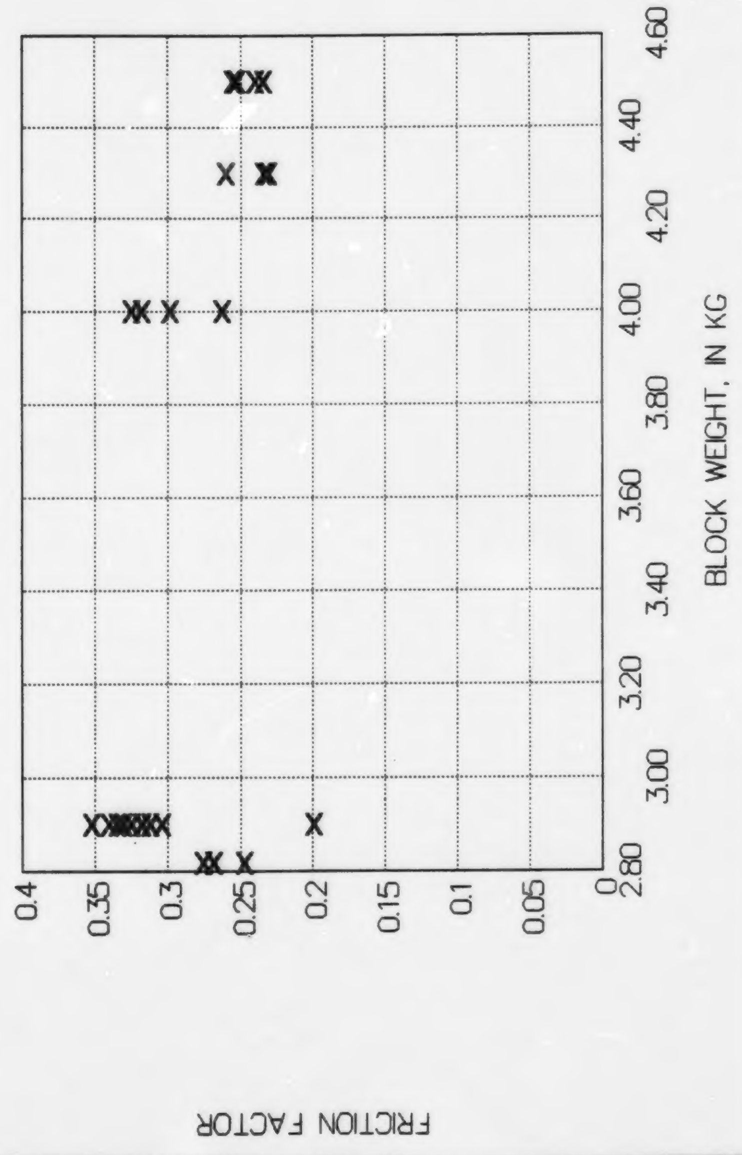
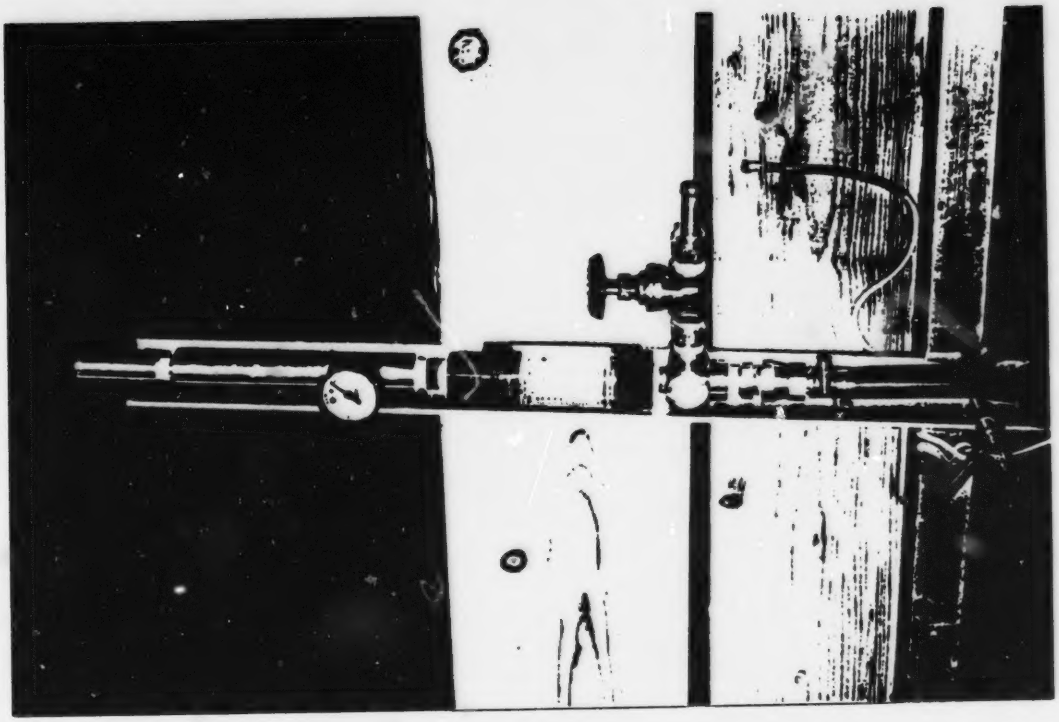
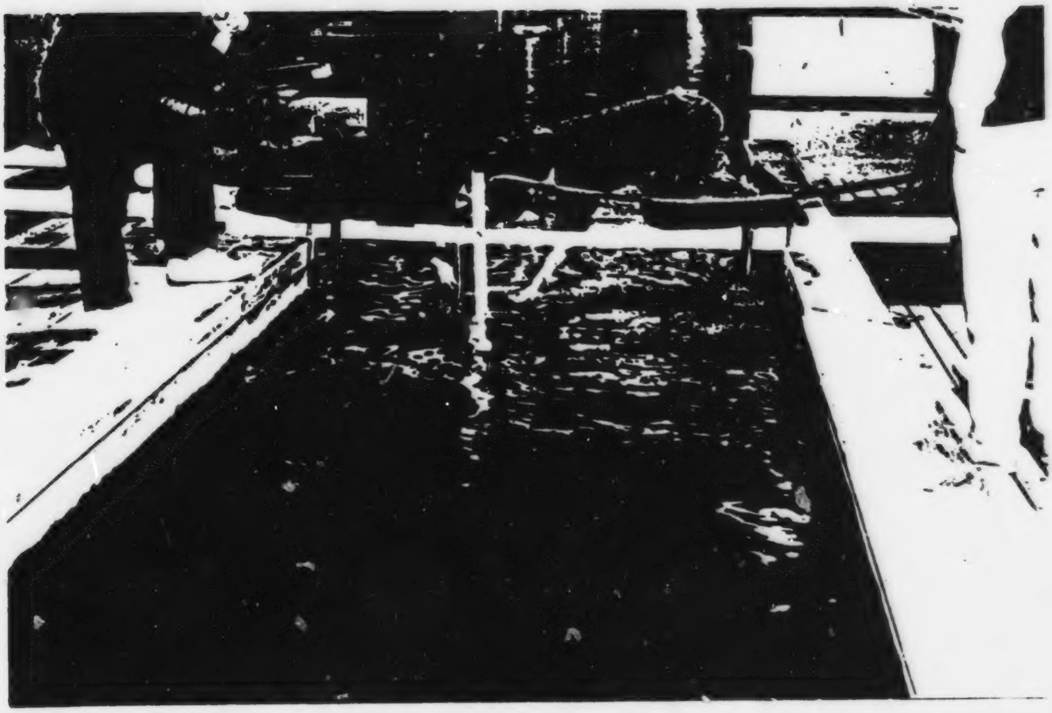


Figure 7.4

FRICTION FACTOR AS A FUNCTION OF BLOCK WEIGHT, WET WAX SURFACE







# 8. WATERJETS TESTS RESULTS

***This chapter is a self - contained document.***

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## *1. OBJECTIVE*

*These tests were conducted in order to establish the potential effectiveness of water jets as ice clearing devices, in addition to the devices being contemplated at the time (fins, deflectors etc).* ***The first step towards this goal*** *was to find out the* ***basic*** *properties of water jets as ice clearing devices.*
*The test series was designed to establish these properties.*

## *2. TESTS SETUP*

*The test rig consisted of the water supply apparatus and the target plate mounted on the instrumented rod, as shown in Figure 2.1.*
*A water supply apparatus was built for the purpose of these tests and consisted of*

*high pressure hose,*
*volumetric flow meter,*
*adapter with the pressure gauge,*
*nozzle.*

*The whole apparatus was submerged 0.5m below the surface for most of the tests.*
*The hose was connected to the fire main, which was pressurized to approx 8 bars at zero flow. The target plate was made of heavy gauge aluminium plate of dimensions 0.3 m X 0.3 m.*

***Tests were conducted on a scale of 1:15.***

*The variables were:*

- *nozzle diameter (3.17mm, 6.35mm, 15.9mm)*
- *water supply volume*
- *distance between the nozzle and the target*
- *depth of submergence*
- *orientation*
- *water/air as a surrounding medium*

*The measuring instruments were of a commercial type, resulting in some scatter of data points.*

## 3. METHOD USED

The water supply was regulated by opening the bypass valve. Readings of the volume and pressure were taken after the flow stabilized. The force on the plate was determined using the calibration curves. The calibration constants are contained in APPENDIX A. Calibrations were done by placing known weights on the plate and reading the resulting bending moment on the rod.

One variable was changed at a time, and the resulting forces were averaged over several seconds of recordings.

Due to the commercial quality of the gauges used, some data on pressure and flow had to be adjusted to give consistent results with the rest of the data set. **Force readings were kept unchanged.** Figure 3.1 shows the flow/ pressure relationships after minor adjustment to some data. Appendix A contains the unadjusted results.

The exit velocity of the jet was calculated using the following formula

$$V = \text{volume } (Q)/\text{area of the orifice } (An) \tag{3.1}$$

Volume was read off the volume meter and converted to SI units.

The static component of the force was calculated using the formula:

$$Fstat = pg * \text{area of the orifice } (An) \tag{3.2}$$

where **pg** is the pressure at the gauge location.
(The diameter of the jet at the gauge location was 9.5 mm.)
The dynamic component of the force was calculated using the formula:

$$Fdyn = ro * V^2/2 * An \tag{3.3}$$

where **ro** is the density of water (taken as 1000 kg/m^3) and **V** is the velocity of the water jet at the exit, computed as above.

The total calculated force is established by combining the static and dynamic components of the force:

$$Ftot = Fstat + Fdyn \tag{3.4}$$

In addition, the theoretical jet force was calculated using the following formula:

$$Fjet = ro * V^2 * An \tag{3.5}$$

Power (at the gauge) was calculated using the expression:

$$P = pg * Q \qquad 3.6$$

*where **pg** was taken from the gauge. Formula for jet power was:*

$$P = 0.5 * ro * Q^3/A^2 \qquad 3.7$$

*Due to the high exponent of volume, this relation was found to give higher scatter and poorer correlations than formula 3.6. Consequently formula 3.6 was used for correlating jet power with other parameters. In ideal conditions, either formula could be used.*

## *4. SCALING LAWS*

*In order to scale up the results of the tests, the proper scaling laws must be selected.*

*This is achieved by realizing the following postulates:*

*4.1. Water used in full scale and model scale has the same mass density, ie*

$$ro\ (\text{model}) = ro\ (\text{full scale}),$$

*and*

*4.2. Linear scale of the testing is preserved, that is:*

$$L\ (\text{model}) = L\ (\text{full scale})/la$$

*where la is the scale factor.*

*4.3. The most important relationships established during the tests must be fulfilled. This relationship is:*

$$\text{Force on the target} = \text{const} * (4 * \text{power of jet}^2 * ro * Ao)^{1/3}$$

*-First postulate leads to the requirement that the mass in full scale is $(la)^3$ times the mass in the model scale.*

*-Second one is a common postulate for the model tests state of the art.*

*-Third postulate can be fulfilled by any number of scaling laws, as it is dimensionally consistent.*

***Froude's scaling law fulfills all three postulates.***

*Consequently we will use it for the purpose of extrapolating the model test results to full scale.*

*The scaling equations are summarized in Table 4.1.*

## *5. RESULTS*

*Table 5.2 summarizes the water jet forces experiments. Twenty nine experiments were made, at three different jet positions:*

*vertical, at 0.5m below the surface*
*horizontal, at 0.5 m below the surface*
*vertical, in air*

*The parameters measured and extrapolated to the full scale are presented in the following table:*

*TABLE 5.1*

*WATERJET PARAMETERS IN MODEL AND FULL SCALE*

| *Parameter* | *unit* | *model scale* | *full scale* |
|---|---|---|---|
| *PRESSURE* | *bar* | *MAX 6.2* | *93.0* |
| | | *AVG 3.4* | *51.0* |
| *FLOW RATE* | *l/min* | *MAX 85* | *74,071* |
| | | *AVG 38* | *33,114* |
| *DISTANCE* | *m* | *MAX 1.0* | *15.0* |
| | | *AVG 0.5* | *7.5* |
| *VELOCITY* | *m/s* | *MAX 35* | *135.0* |
| | | *AVG 21* | *81.0* |
| *ORIFICE DIAMETER* | *m* | *MAX 0.01587* | *0.238* |
| | | *MED 0.00635* | *0.095* |
| | | *SML 0.01587* | *0.238* |
| *JET FORCE* | *N* | *MAX 26.4* | *89,100* |
| | | *AVG 16.0* | *54,000* |
| *POWER** | *W* | *MAX 440* | *5,751,381* |
| | | *AVG 201* | *2,627,000* |

** Defined as:*
$P = \rho g * Q$

## 5.1 **Calculated/measured values**

*The first step taken was a comparison of the forces measured with those calculated using two different approaches:*

1. *Calculating static and dynamic force components and adding them up (see formulas 3.2 & 3.3), and*
2. *Calculating total theoretical jet force (see formula 3.5)*

*Comparison of these forces with the measured ones is given in Table 5.3.*

*Inspection of the table reveals that:*

1. *There exists a* ***good agreement between the calculated and*** *measured forces, for both methods of calculation.*
2. *Average ratio of* ***measured to calculated (method 1) force*** *is*

   ***0.86***

   *For the jet method, the ratio is*

   ***0.93***

   *The ratios are less than one due to the non-ideal liquid losses, presence of the water medium, and other effects.*

3. *The jet force method gives slightly higher scatter than the calculated force method. This is understandable, since this method relies on the reading of one gauge only (flow meter).*

*Figure 5.1 shows the relationship between the static, dynamic and the total force measured for all data. It is clear that the* ***static and dynamic components of the force are approximately equal to 1/2 of the total force.***

*Figure 5.2 shows the force on the target as a function of pressure for the forces*

*measured, and*
*calculated using method 1, and*
*calculated using method 2,*

*for the medium size nozzle.*

*The agreement with calculations is good.*
*Note the nearly linear dependence of force on pressure. The theory gives linear dependence on the pressure.*

*The following can be noted:*

1. *The relationship between the calculated and measured force is linear.*

2. *Both methods give good results.*

3. *The jet force method gives good overall results.*

4. *For high magnitude forces, the discrepancy between the measured and calculated forces is lower than for the low magnitude forces.*

*Figure 5.3 shows the static and dynamic components of the total calculated force as compared to 1/2 of the total measured force. The values compare well with those measured.*

*Consequently, either formula can be used for the computation of the force on the target.*

### ***5.2 Flow rate/pressure***

*Figures 5.4 to 5.8 show the measured flow rate versus pressure. Following observations can be made:*

1. *Flow rate grows proportionally to the pressure, for all nozzles.*

2. *For the same pressure of 4 bars, a small nozzle throttles the flow from nearly 50 l/m for a medium size, to 13 l/min. (a factor of 3)*

3. *The distance of 0.5m between the target and the nozzle gives higher flows (for the same pressure) than the 0.2m or 1.0m distance.*

4. *For the same pressure, the medium nozzle in water discharged more volume than in air. This may be attributed to the difference in levels at which the nozzle was located in these tests:*

   *0.5m above water for tests in air, and*
   *0.5m below water for tests in water.*

## 5.3 Maximum pressure/nozzle orifice area

Due to the limitations of the water supply, the maximum pressure achievable was 6.2 bars. Extrapolated to the zero flow condition, the watermain pressure was 8 bars. The maximum pressure variation as a function of the nozzle area is shown in Figure 5.9. A quick drop of the pressure with increased nozzle area is evident. As the large nozzle opening was larger than the I.D. of the adaptor, the pressure measured for this nozzle had to be extrapolated to a value of 4 bars.

## 5.4 Maximum force/distance to target

Table 5.4. summarizes the maximum force measured on the target as a function of the distance. The force on the target decreases with the distance to the target, for the range measured. This follows the trend published in the hydraulic handbooks, an extract from which is shown in Figure 5.10.
This relationship is graphically shown in Figure 5.11, for all three nozzles.
The examination of this graph leads to the following conclusions:

1. Force on the target drops with an increase in the distance.
2. The drop is nearly a linear one.
3. A small nozzle suffers a proportionately larger drop than the larger ones.
4. Medium and large nozzles show the same drop.
5. Within the short distances (up to 0.5m model scale and 7.5m full scale) the drop is small and can be ignored in the first approximation.

## 5.5 Force/pressure

This relationship is shown in the Figure 5.2. The dependence is nearly a linear one, in the range tested.

Conclusions:

1. Force is proportional to the pressure.
2. For the short distances, the increase of force with the increase of pressure is more pronounced than for the long distances.

## 5.6 Force/orifice area

The correlation is shown in the Figure 5.12, for the three distances tested. Force increases are nearly in proportion to the nozzle area from zero to 0.03 * 10^-3 m^2 and then level off. This is due to the rapid loss of pressure associated with the increase of the nozzle area (Figure 5.9) and the limiting maximum line pressure of 8 bars. Theoretical correlation is a straight line (for constant pressure).

### *5.7 Force/distance*

*This relationship is shown in Figure 5.13 for the 0.5 m and 1 m distance and in the Figure 5.14 for 0.2 m and 1 m distance. Doubling of the distance reduces the force by 33% at 2 bars pressure and by 27% at 6 bars pressure.*

*Conclusion:*

***The higher the pressure, the less important is the distance** between the nozzle and the target.*

### *5.8 Force/medium*

*The difference between the force in water and in air is shown (for the 0.2 m distance) in Figure 5.14. The difference is consistent. Part of the difference may be attributed to the higher discharge rate in water (see preceding paragraphs).*

*Conclusions:*

1. *Force on the target in water is larger than the force on the target in air.*
2. *The difference could be attributed to the entrained water effect, but there is no sufficient data to verify this hypothesis.*

## 5.9 Force/power

In order to find out about the powering requirements for the water jets, the jet power was calculated using the formula 3.6 The results are shown in Table 5.6. Shown also are the values of the force calculated using the **power** as an input variable:

$$F = (4 * Power^2 * ro * An)^{1/3} \quad \ldots\ldots 5.1$$

Very consistent results were obtained using this relationship for the three distances used. The results of the regression analysis are shown in Table 5.7. Correlation coefficients R are shown in the following table:

TABLE 5.8

FORCE/POWER CORRELATION COEFFICIENTS R

| distance nozzle/target | R |
|---|---|
| 0.2 m | 0.9953 |
| 0.5 m | 0.9971 |
| 1.0 m | 0.9931 |

An inspection of the table shows that the correlation is very strong. Large nozzle data is not included in these regressions due to the suspected inaccuracies of the gauge readings.

Figures 5.15, 5.16 and 5.17 show the dependencies between the forces calculated using the above power relationship and the measured forces on the target.

Conclusions:

1. Force on the target plate due to impinging jet is proportional to the

   $$(\text{power of the jet})^{2/3}.$$

2. The equation linking the jet power, orifice area and the mass density of the liquid to the force on the target is:

   $$F\ target = C * (4 * Jet\ power^2 * ro * An)^{(1/3)} \quad \ldots 5.2$$

3. The coefficient C depends on the distance of the nozzle to the target. Table 5.9 shows the results of the coefficient C/distance regression, and Table 5.10 the correlation coefficients R.

TABLE 5.10

COEFFICIENT C AS A FUNCTION OF DISTANCE

| Distance<br>m | C coefficient<br>- |
|---|---|
| 0.2 | 0.968 |
| 0.5 | 0.868 |
| 1.0 | 0.700 |

4. The dependence of the force on the distance is a linear one, in the range tested. Figure 5.18 shows the regressed coefficient C versus distance. The correlation coefficient is

**0.9991.**

The equation for the influence of the distance on the magnitude of the force is:

$$C = 1.03 - 0.3343 * DISTANCE \qquad \text{5.3}$$

Although the distance should be put in meters, the coefficient is a non dimensional one.

5. Zero thrust distance can be estimated from the above formula as:

$$d_o = 3.1 \text{ m (model scale)}$$

for the range of powers tested.

6. Thrust at zero distance can be estimated as:

$$F(d=0) = 1.03 * (4*power^2 * ro *area)^{1/3} \qquad \text{5.4}$$

Theoretical constant C should be equal to 1.

**This formula is recommended for the calculations of the** waterjet forces in full scale.

It should be noted that the power used in the above computations is the power **before the jet orifice**. Use of the jet power after the orifice, expressed by formula 3.7, gave poorer correlations, due to higher scatter of the data. When using the test results for the full scale prediction of jet forces, the difference between the nozzle losses as tested, and as used in full scale, should be accounted for.

## 5.10 Jet efficacy

In a full analogy to the propeller thrust, the waterjet thrust can be compared to the power of the jet, and the power of the machinery needed to generate this jet.

The jet efficacy is defined as:

$$\text{Jet thrust/jet power} \tag{5.5}$$

Jet power can be established as follows:

$$\text{Power} = ptot * Q \tag{5.6}$$

For the ideal hydraulic system, having an unlimited water supply and constant pressure (large tank with small orifice at the bottom), **the ideal efficacy** of the system can be computed as follows:

$$\text{Maximum achievable jet thrust} = ptot * An$$

$$\text{Jet power} = ptot * Q$$

$$Q = V * An$$

$$V = (2 * ptot/ro)^{0.5}$$

Putting these expressions into the formula we will obtain the following expressions for the jet efficacy, in SI units:

SYSTEM HEAD IS KNOWN

$$\mathbf{Thrust/Power = (2*ro/(ptot)^{0.5}} \tag{5.7}$$

EXIT VELOCITY IS KNOWN

$$\mathbf{Thrust/Power = 2/Vjet} \tag{5.8}$$

DISCHARGE IS KNOWN

$$\mathbf{Thrust/Power = 2 * An / Q} \tag{5.9}$$

POWER IS KNOWN

$$\mathbf{Thrust/Power = (4*ro/An/Power)^{1/3}} \tag{5.10}$$

where ptot is the maximum pressure of the system (equal to gamma * H), expressed in pascals, ro is the density of water, An is the nozzle orifice area, and Q is the discharge volume, in $m^3$/sec.

*Important conclusions are derived from these formulas:*

1. ***Ideal efficacy drops with an increase of the exit velocity.***
2. ***Ideal efficacy drops with an increase of the total pressure.***
3. ***Ideal efficacy increases with an increase in orifice area.***
4. *All variables can be reduced to one, that is the exit velocity of the jet:*

***Thrust/Power = 2/Vj***

*This dependence is shown in Figure 5.19.*

*For the tests conducted, the jet efficacies are tabulated in the TABLE 5.11, for the model and full scale.*

*The following observations can be made:*

1. *Average jet efficacy increased with an increase in the orifice area. This is attributed to the drop of line pressure in the system, and the frictional losses at the nozzles. Figure 5.20 illustrates the trend.*
2. *The maximum efficacy of the jet was 9.96 kG/HP, for the medium size nozzle.*
3. ***The efficacy of the full scale system drops*** *when compared with the model scale system by a factor of (la)^-0.5. This is so because the pressure of the full scale system grows in proportion to the scale of the system. In reality, only incremental pressure increase is needed, hence the efficacy will be much higher than shown.*

## 5.11 Hydraulic properties of the adaptor/nozzle used.

Since the pressure was measured at the adaptor, we can calculate only the parameters "down the stream", ie adaptor and nozzle together.

The coefficient of velocity for the assembly is calculated as follows:

cv = mean velocity/(2 * pg/ro)^0.5....................5.11

Power loss factor can be calculated by relating the power before the nozzle to the jet power after the nozzle:

lf = Power before/ power after = Q *p/Q * ro * V.......5.12

Coefficient of discharge is equal to the coefficient of velocity, under the assumptions stated.
Table 5.12 gives the coefficients of discharge and power loss factor for all the tests.
The average values of the coefficients are:

TABLE 5.13

HYDRAULIC COEFFICIENTS OF THE WATERJET NOZZLES

| nozzle size | dn/ pipe dia | discharge coefficient | power loss factor lf |
|---|---|---|---|
| small | 0.33 | .11 | 1.04 |
| medium | 0.67 | .42 | 1.20 |
| large | 1.00 | .96 | 1.09 |

These coefficients compare resonably well with the wall orifice discharge coefficient of 0.6.

Figure 5.21 shows the coefficient as a function of orifice area for the small, medium and large nozzles.

The following observations are made:

1. The larger the nozzle, the larger its discharge coefficient. This trend is identical to the ones given in hydraulic handbooks.

2. The values of the discharge coefficient obtained in the experiments compare well with those given in the handbooks for coefficients of discharge for sharp circular openings (cv= 0.6 for the medium size nozzle).

## 6. EXAMPLE OF APPLICATION

*Fire monitor pump from an existing icebreaking ship:*

| | |
|---|---|
| *Discharge Q:* | *300 $m^3/hr$ (0.0833 $m^3/s$)* |
| *Pressure p:* | *920 kPa* |
| *Available power $P = Q * p$:* | *77 kW.* |

*Jet power can be calculated using the following formula:*

$$P = 0.5 * ro * Q^3/A^2 \quad \text{(formula 3.7)}$$

*As this power must be equal to the delivered power, the orifice area can be calculated as follows:*

$$Aj = (ro * Q^3/2/P * lf)^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots 6.1$$

*Model tests gave the average loss of power at the orifice as 13% ($lf = 1.13$)*

*This yields the orifice area of 0.0021 $m^2$, and the jet speed of*

$$Vj = 39.7 \text{ m/s}$$

*The jet force at zero distance can be calculated from:*

$$Fj = 1.03 * (4 * ro * P^2 * A)^{1/3} = ro * V^2 * A$$

$$Fj = 3.39 \text{ kN}$$

*The efficacy of the jet is:*

$$eff = 2/Vj = F/P = (2*ro/p)^{0.5} = \ldots\ldots\ldots\ldots\ldots\ldots 6.2$$

$$eff = 3.3 \text{ kG/HP}$$

*Nozzle diameter is 52 mm.*

*The force at a distance of 5m can be calculated as follows:*

*The distance of 5 m corresponds to the model scale of 1/15 = 0.333m.*

*The C constant for that value is:*

$$C = 1.03 - 0.3343*0.333 = 0.92$$

*Force at a distance of 5m is therefore:*

$$F(5) = F(0) *0.92 = 3.4 * 0.92 = 3.13$$

*Using the handbook charts (ref 1), the force exerted by the jet emitted from a nozzle of 52 mm dia, at a pressure of 9.2 bars is:*

*3.0 kN at 5 m distance,*

*Considering the simplifying assumptions made, the agreement found is satisfactory.*

*One of the possible arrangements of the nozzle arrays on an icebreaking ship is shown in Figure 6.1.*

*The jets can fulfill the following functions:*

1. *Break up the "ice arc" composed of broken ice pieces lying on the shell and connected edge to edge, thus speeding up the surfacing of the ice blocks . This in turn should lead to:*

   *lowering of the frictional component of resistance and less ice ingestion into propellers.*

2. *Pushing ice away from the hull thus:*

   *speeding ice block surfacing (see chapter on float-up tests), and*
   *less ice ingestion in the propellers is a likely result.*

3. *Pushing ice away from the side shell and or bottom of the ship away from the boundary layer permits the complete dis-engagement of ice from the hull thus resulting in a clearer channel and less ice ingestion into propellers.*

4. *Comparison of the conclusions derived in this chapter with ice floe drag experiments leads to the following conclusion:*

   *Waterjets can deliver a substantial "punch" to the ice floe passing by the jet orifice. However this punch should not be in one giant impulse, as the floe would quickly attain the critical velocity and would not move away appreciably. Instead, a series of small "blows" should gently accelerate the ice block, always:*

   ***below the critical speed.***

### Recommended procedure

*(**Applicable only to the stationary medium and the range of** parameters tested).*

1. *For a series of assumed impulses, calculate the motion of ice block and assure that **it falls below the critical speed** (see chapter on float-up tests), at which its motion becomes unstable. This gives the maximum jet thrust needed to propel the block.*

2. *For that thrust of the jet, compute the power of the jet using the power formula and a series of assumed orifice areas. The distance coefficient can be set initially to 1.*

   *JET POWER = 0.5 * (Thrust^3/Area/ro)^0.5*

3. *Compute the pump power needed to generate the above calculated jet power, assuming normal line losses, pump efficiency etc.*

4. *Correct for the distance required by increasing the jet power and pump power using the proper distance coefficient.*

5. *Use the largest possible nozzle, low pressure and large volume pumps.*

## *7. SUMMARY OF CONCLUSIONS FROM WATERJET TESTS*

### General

1. *Test method was successful and yielded useful information about the thrust of submerged jets.*

   *Maximum thrust measured was 26.4 N*
   *Maximum power developed by the jet was 440 Watts.*

2. *Froude's Scaling Laws can be applied to extrapolate the model tests results to the full scale applications.*

   *Thrust of the jet scales up with* $(la)^3$

   *Power of the jet scales up with* $(la)^{3.5}$

### Analytical computations

1. *Calculations of the jet force by means of adding of static and dynamic components gives good results.*

2. *Calculations of the force using the jet force formula is a good approximation in the whole range tested.*

   $$F = 1025 * V^2 * \text{orifice area}$$

   *(all dimensions in SI units)*

3. *Force on the target can be computed in a first approximation by using the power of the jet as follows:*

   $$F = C * (4 * (\text{Jet power})^2 * ro * \text{Orif area})^{1/3}$$

   *where C is the distance coefficient computed from:*

   $$C = 1.03 - 0.3343 * \text{distance},$$

   *Above formula is valid only for the range of powers tested.*

### Maximum force/distance

*The force on the target drops proportionately with the distance from the target.*

*The drop is small for medium and large size nozzles and for small size nozzle. Drop is linear, for the range tested.*

### Maximum force/nozzle area

*Increasing the nozzle area increases the force until a cut off is achieved due to the limitations of the system supply.*

***Maximum force/ pressure***

*The maximum force on the target increases nearly proportionately with the pressure in the system.*

***Maximum force/ medium***

*The maximum force in water is larger than the maximum force in air.*

***Efficacy of the system***

*Nozzles used in these tests were of simple design, hydraulically comparable to the sharp edge opening in a wall of a tank.*

*The average (for all the tests) thrust/power efficacy coefficient of the jet increases linearly with the increase of nozzle aperture area.*

*For the nozzle tested, average efficacy was 6.15 KG/HP for the medium nozzle. Maximum efficacy was achieved with the medium size nozzle, of 11.9 kG/HP. The efficacy coefficient in the full scale are expected to be (for same nozzle designs) of the order of 1.6 kG/HP.*

*These coefficients can be significantly improved with optimization of nozzle design.*

*Efficacy drops with an increase of the system pressure. Ideal efficacy is:*

$$T/\text{Jet power (kG/HP)} = 150/V_j$$

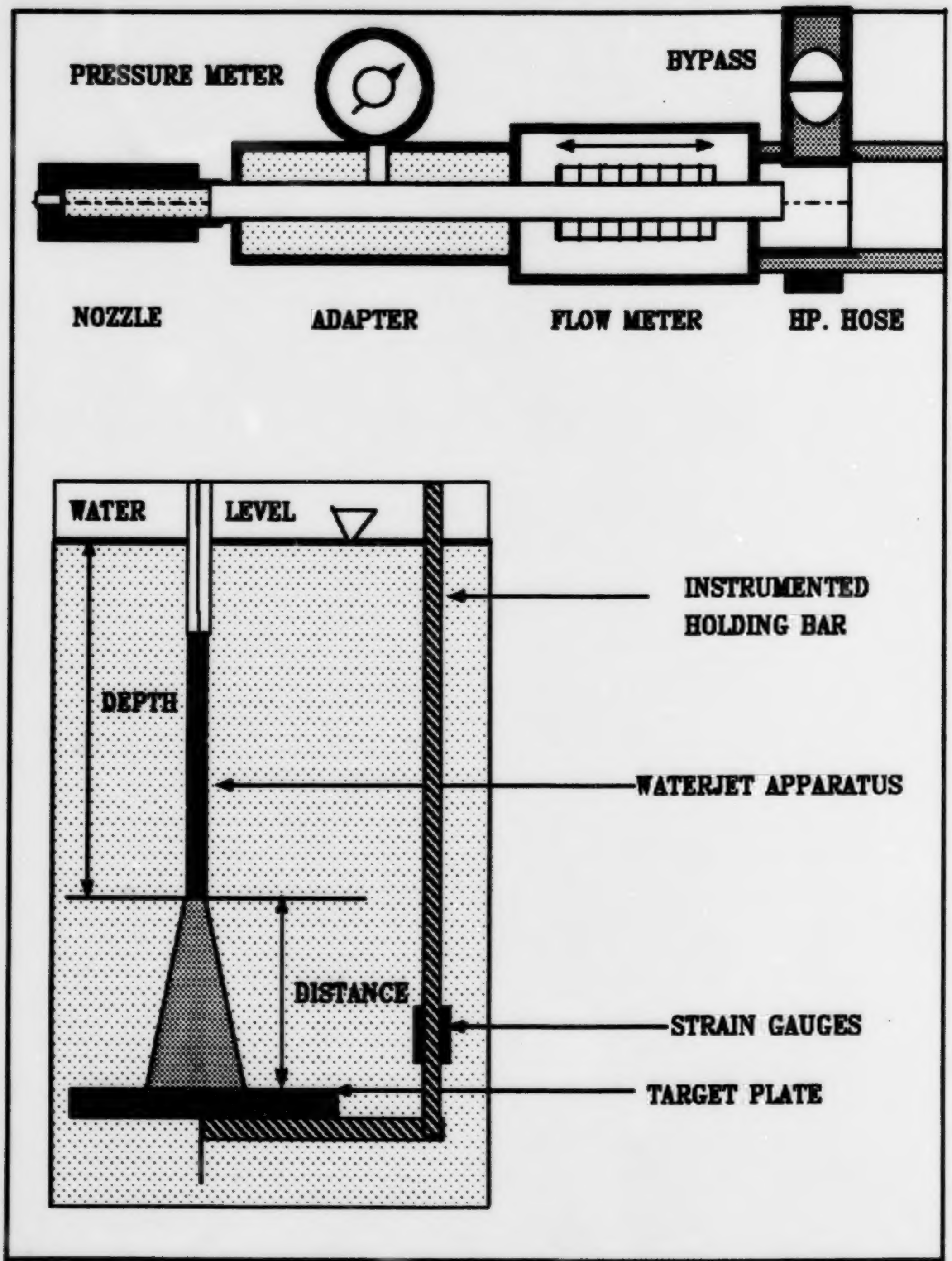
## 8. RECOMMENDATIONS

1. Using the apparatus already available, a test series aimed at the establishment of the influence of the medium cross - velocity on the effectiveness of the jet thrust should be conducted.
2. Efficient nozzles should be designed for high efficacy coefficients.
3. Motions of ice blocks under the water jet impacts should be established.
4. A waterjet system should be mounted onboard the ship model and its effectiveness as an ice clearing device studied.

## 9. REFERENCES

1. Pipe Designers Handbook, courtesy P. Semery, TDC

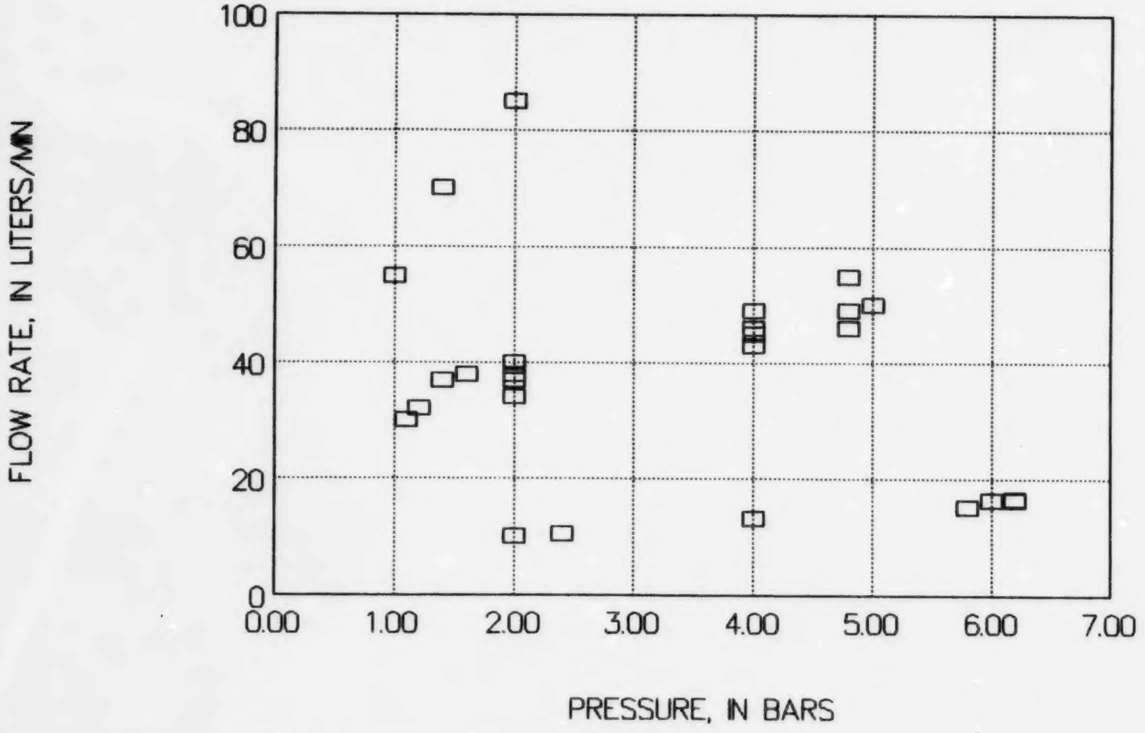
FIGURE 8.2.1



| | | | |
|---|---|---|---|
| **FIGURE TITLE:** WATER JET TESTS SETUP | | | |
| **PROJECT NAME:** BLOCKAGE INVESTIGATIONS | | | **PROJECT NR:** |
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 2.1 |

FLOW AS A FUNCTION OF PRESSURE

ALL DATA



## *TABLE 8.5.1*

## *SCALING LAWS FOR WATERJET TESTS*

*la = full scale length/ model scale length*

| *parameter* | *unit* | *model scale* | *full scale* |
|---|---|---|---|
| *ORIFICE AREA* | *m^2* | *An* | *(la)^2 * An* |
| *WATER FLOW RATE* | *m^3/sec* | *Q* | *(la)^2.5 * Q* |
| *PRESSURE* | *Pa* | *p* | *(la) * p* |
| *FORCE ON TARGET* | *N* | *F* | *(la)^3 * F* |
| *DISTANCE TO TARGET* | *m* | *d* | *(la) * d* |
| *WATERJET VELOCITY* | *m/s* | *V* | *(la)^0.5 * V* |
| *TIME* | *s* | *t* | *(la)^0.5 * t* |
| *JET POWER* | *Watts* | *P* | *(la)^3.5 * P* |
| *JET EFFICACY* | *s/m* | *F/P* | *(la)^-0.5 * F/P* |

*The scaling laws are analogous to the propeller thrust scaling laws used commonly in model testing. They are also compatible with the Froude's Scaling Law used elsewhere in this project. Scale of the tests was 1:15, in order to make the results compatible with the other testing programme components.*

## TABLE 8.5.2

## WATER JET FORCES EXPERIMENTS SUMMARY

WATER JET FORCE IN NEWTONS

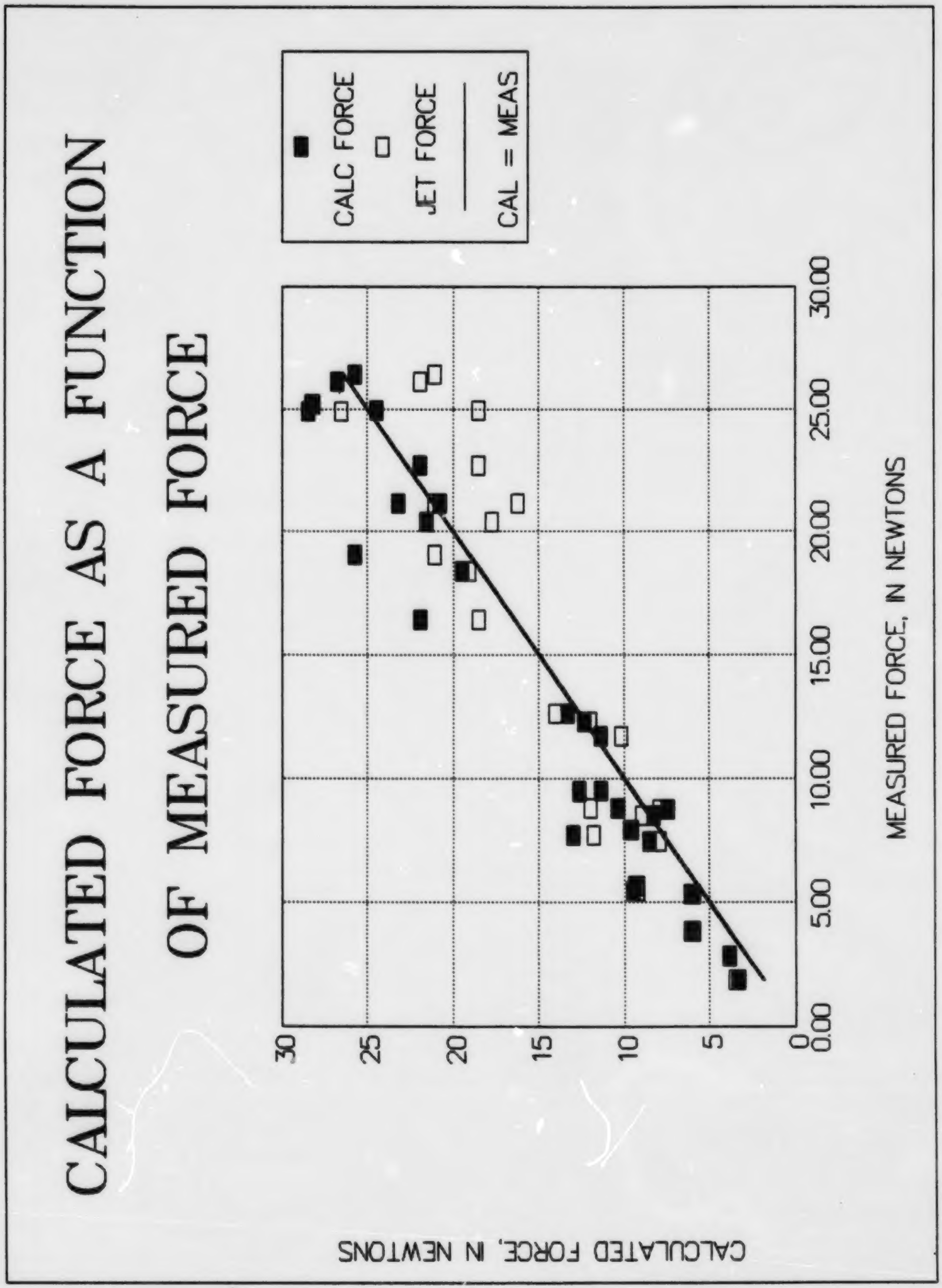
| | PRESSURE | FLOW RATE | DISTANCE | VELOCITY | ORIFICE DIAMETER, IN METERS | | |
|---|---|---|---|---|---|---|---|
| | BARS | L/M | M | M/S | 0.003175 | 0.00635 | 0.009525 |
| | p | Q | d | V | | | |
| # | POSITION OF THE JET: VERTICAL, AT 0.5M BELOW THE WATER LEVEL | | | | | | |
| 1 | 1.40 | 37.00 | 0.50 | 19.47 | | 8.79 | |
| 2 | 1.60 | 38.00 | 0.50 | 20.00 | | 9.48 | |
| 3 | 2.00 | 40.00 | 0.50 | 21.05 | | 12.64 | |
| 4 | 4.00 | 49.00 | 0.50 | 25.79 | | 21.15 | |
| 5 | 4.80 | 55.00 | 0.50 | 28.94 | | 24.90 | |
| 6* | 1.00 | 55.00 | 0.50 | 12.86 | | | 7.70 |
| 7* | 2.00 | 85.00 | 0.50 | 19.88 | | | 25.20 |
| 8 | 2.40 | 10.50 | 0.50 | 22.10 | 2.82 | | |
| 9 | 4.00 | 13.00 | 0.50 | 27.37 | 5.34 | | |
| 10 | 5.80 | 15.00 | 0.50 | 31.58 | 7.47 | | |
| 11 | 6.20 | 16.50 | 0.50 | 34.73 | 7.92 | | |
| 12 | 2.00 | 10.00 | 1.00 | 21.05 | 1.87 | | |
| 13 | 4.00 | 13.00 | 1.00 | 27.37 | 3.83 | | |
| 14 | 6.00 | 16.20 | 1.00 | 34.10 | 5.65 | | |
| 15 | 6.20 | 16.20 | 1.00 | 34.10 | 5.43 | | |
| 16* | 1.40 | 70.00 | 1.00 | 16.37 | | | 18.40 |
| 17 | 2.00 | 38.00 | 1.00 | 20.00 | | 9.44 | |
| 18 | 4.00 | 46.00 | 1.00 | 24.21 | | 16.41 | |
| 19 | 4.80 | 49.00 | 1.00 | 25.79 | | 19.05 | |
| 20 | 1.20 | 32.00 | 0.20 | 16.84 | | 8.50 | |
| 21 | 2.00 | 37.00 | 0.20 | 19.47 | | 12.30 | |
| 22 | 4.00 | 46.00 | 0.20 | 24.21 | | 22.70 | |
| 23 | 5.00 | 50.00 | 0.20 | 26.31 | | 26.10 | |
| | POSITION OF THE JET: HORIZONTAL, AT 0.5 M BELOW THE WATER LEVEL | | | | | | |
| 24 | 4.00 | 45.00 | 0.20 | 23.68 | | 20.40 | |
| 25 | 4.80 | 49.00 | 0.20 | 25.79 | | 26.40 | |
| | POSITION OF THE JET: VERTICAL, IN AIR | | | | | | |
| 26 | 1.10 | 30.00 | 0.20 | 15.79 | | 8.73 | |
| 27 | 2.00 | 34.00 | 0.20 | 17.89 | | 11.71 | |
| 28 | 4.00 | 43.00 | 0.20 | 22.63 | | 21.14 | |
| 29 | 4.80 | 46.00 | 0.20 | 24.21 | | 24.94 | |
| MAX | 6.20 | 85.00 | 1.00 | 34.73 | 7.92 | 26.40 | 25.20 |
| AVG | 3.40 | 37.39 | 0.52 | 21.36 | 4.48 | 16.93 | 17.10 |

NOT RELIABLE READINGS

## TABLE 8.5.3

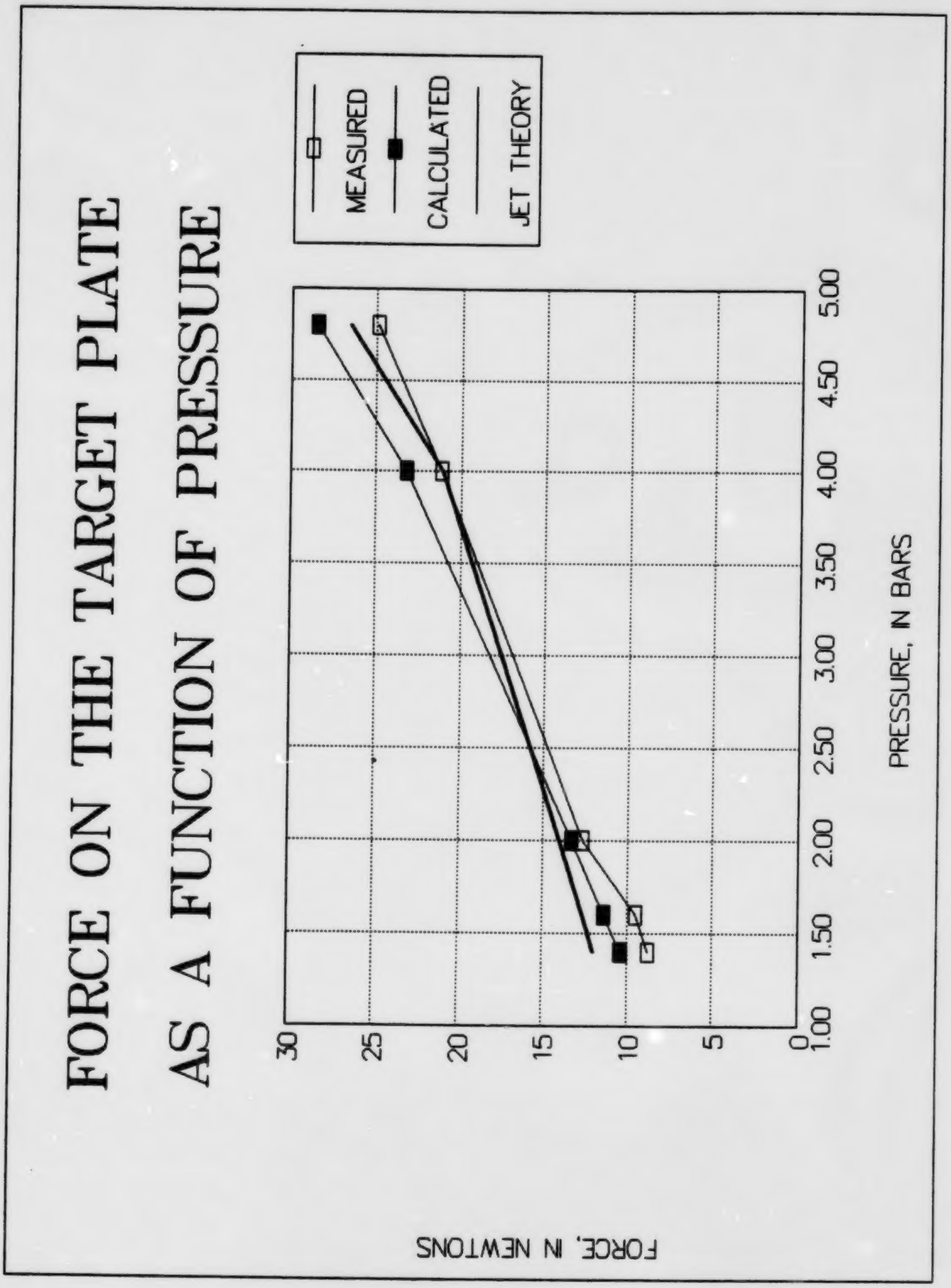
## STATIC AND DYNAMIC FORCE COMPONENTS

| | DYNAMIC PRESSURE RO*V^2/2 PA pd | STATIC PRESSURE GAUGE PA pg | DYN FORCE pd*An N Fd | STAT FORCE p*An N Fstat | TOTAL STAT+ DYN FORCE N Ftot | MEASURED FORCE N F | MEASURED /CALC FORCE - F/FTOT | JET FORCE N Fjet | MEAS'D /JET FORCE - F/FJET |
|---|---|---|---|---|---|---|---|---|---|
| | 189,581 | 140,000 | 6.00 | 4.43 | 10.44 | 8.79 | 0.84 | 12.01 | 0.73 |
| | 199,967 | 160,000 | 6.33 | 5.07 | 11.40 | 9.48 | 0.83 | 12.67 | 0.75 |
| | 221,570 | 200,000 | 7.02 | 6.33 | 13.35 | 12.64 | 0.95 | 14.03 | 0.90 |
| | 332,493 | 400,000 | 10.53 | 12.67 | 23.20 | 21.15 | 0.91 | 21.06 | 1.00 |
| | 418,906 | 480,000 | 13.27 | 15.20 | 28.47 | 24.90 | 0.87 | 26.53 | 0.94 |
| | 82,747 | 100,000 | 5.90 | 7.13 | 13.02 | 7.70 | 0.59 | 11.79 | 0.65 |
| | 197,635 | 200,000 | 14.08 | 14.25 | 28.33 | 25.20 | 0.89 | 28.17 | 0.89 |
| | 244,281 | 240,000 | 1.93 | 1.90 | 3.83 | 2.82 | 0.74 | 3.87 | 0.73 |
| | 374,453 | 400,000 | 2.96 | 3.17 | 6.13 | 5.34 | 0.87 | 5.93 | 0.90 |
| | 498,532 | 580,000 | 3.95 | 4.59 | 8.54 | 7.47 | 0.87 | 7.89 | 0.95 |
| | 603,224 | 620,000 | 4.78 | 4.91 | 9.68 | 7.92 | 0.82 | 9.55 | 0.83 |
| | 221,570 | 200,000 | 1.75 | 1.58 | 3.34 | 1.87 | 0.56 | 3.51 | 0.53 |
| | 374,453 | 400,000 | 2.96 | 3.17 | 6.13 | 3.83 | 0.62 | 5.93 | 0.65 |
| | 581,488 | 600,000 | 4.60 | 4.75 | 9.35 | 5.65 | 0.60 | 9.21 | 0.61 |
| | 581,488 | 620,000 | 4.60 | 4.91 | 9.51 | 5.43 | 0.57 | 9.21 | 0.59 |
| | 134,036 | 140,000 | 9.55 | 9.98 | 19.53 | 18.40 | 0.94 | 19.10 | 0.96 |
| | 199,967 | 200,000 | 6.33 | 6.33 | 12.67 | 9.44 | 0.75 | 12.67 | 0.75 |
| | 293,026 | 400,000 | 9.28 | 12.67 | 21.95 | 16.41 | 0.75 | 18.56 | 0.88 |
| | 332,493 | 480,000 | 10.53 | 15.20 | 25.73 | 19.05 | 0.74 | 21.06 | 0.90 |
| | 141,805 | 120,000 | 4.49 | 3.80 | 8.29 | 8.50 | 1.03 | 8.98 | 0.95 |
| | 189,581 | 200,000 | 6.00 | 6.33 | 12.34 | 12.30 | 1.00 | 12.01 | 1.02 |
| | 293,026 | 400,000 | 9.28 | 12.67 | 21.95 | 22.70 | 1.03 | 18.56 | 1.22 |
| | 346,203 | 500,000 | 10.96 | 15.83 | 26.80 | 26.10 | 0.97 | 21.93 | 1.19 |
| | 280,424 | 400,000 | 8.88 | 12.67 | 21.55 | 20.40 | 0.95 | 17.76 | 1.15 |
| | 332,493 | 480,000 | 10.53 | 15.20 | 25.73 | 26.40 | 1.03 | 21.06 | 1.25 |
| | 124,633 | 110,000 | 3.95 | 3.48 | 7.43 | 8.73 | 1.17 | 7.89 | 1.11 |
| | 160,084 | 200,000 | 5.07 | 6.33 | 11.40 | 11.71 | 1.03 | 10.14 | 1.15 |
| | 256,052 | 400,000 | 8.11 | 12.67 | 20.78 | 21.14 | 1.02 | 16.22 | 1.30 |
| | 293,026 | 480,000 | 9.28 | 15.20 | 24.48 | 24.94 | 1.02 | 18.56 | 1.34 |
| MIN | 0 | 100,000 | 1.75 | 1.58 | 3.34 | 1.87 | 0.56 | 3.51 | 0.53 |
| AVG | 293,077 | 339,655 | 7.00 | 8.36 | 15.36 | 13.67 | 0.86 | 13.99 | 0.93 |
| MAX | 603,224 | 620,000 | 14.08 | 15.83 | 28.47 | 26.40 | 1.17 | 28.17 | 1.34 |



CALCULATED FORCE AS A FUNCTION OF MEASURED FORCE

FIGURE 8.5.2



FORCE ON THE TARGET PLATE AS A FUNCTION OF PRESSURE

FIGURE 8.5.3

## STATIC FORCE AND DYNAMIC FORCE CALCULATED AND MEASURED VALUES

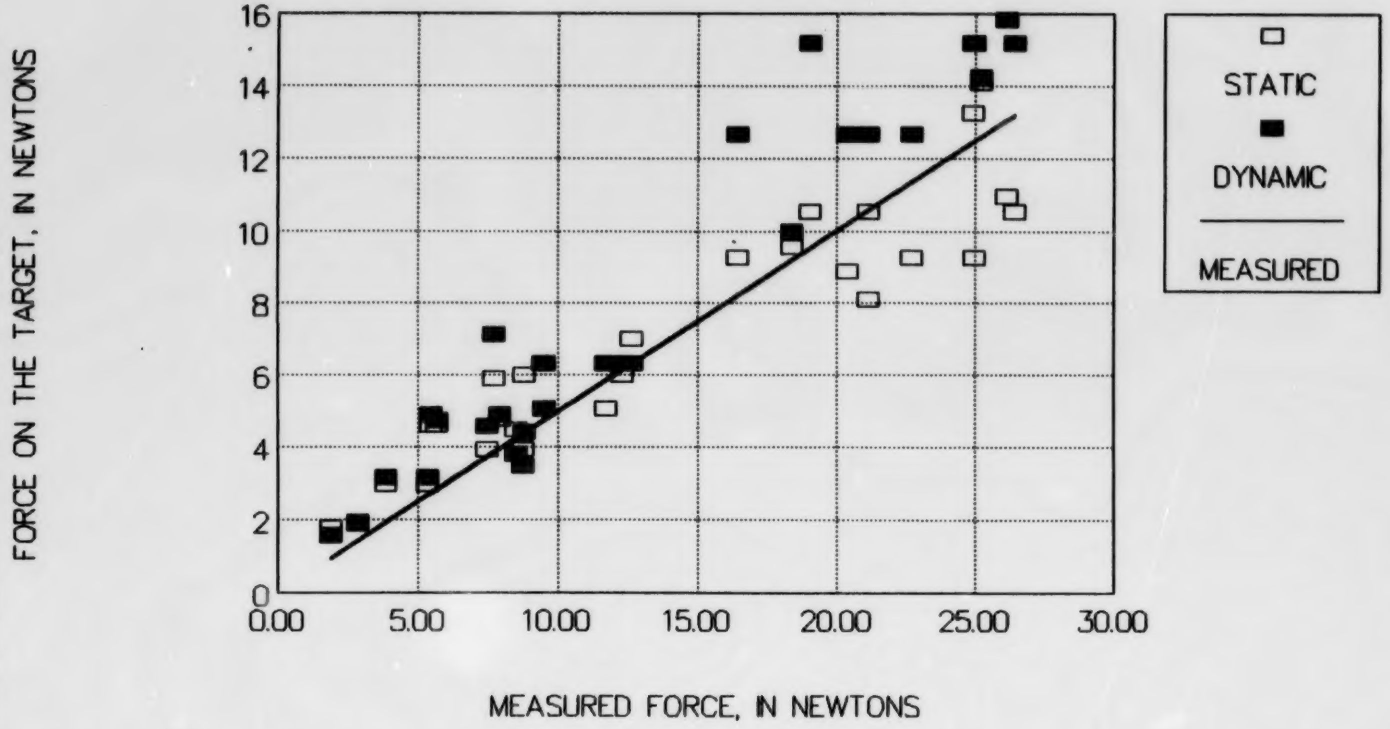
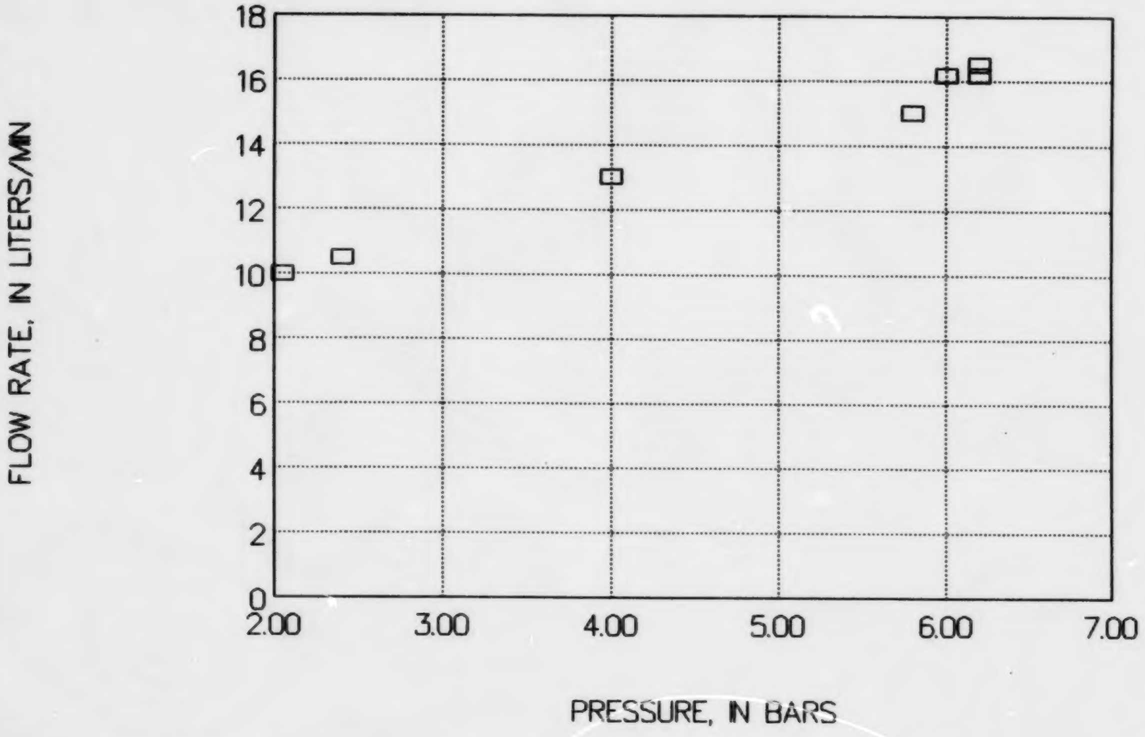
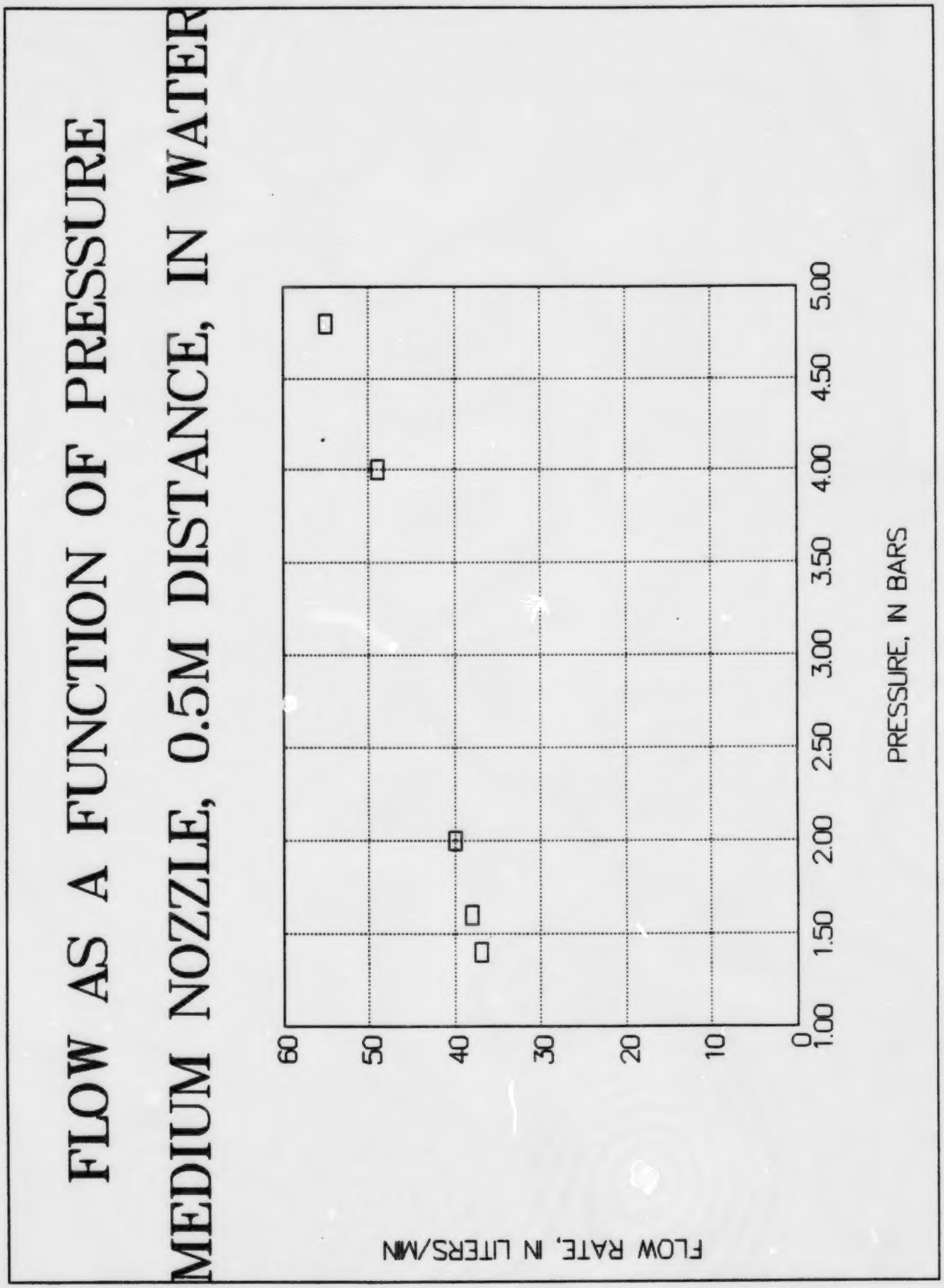


FIGURE 8.5.4

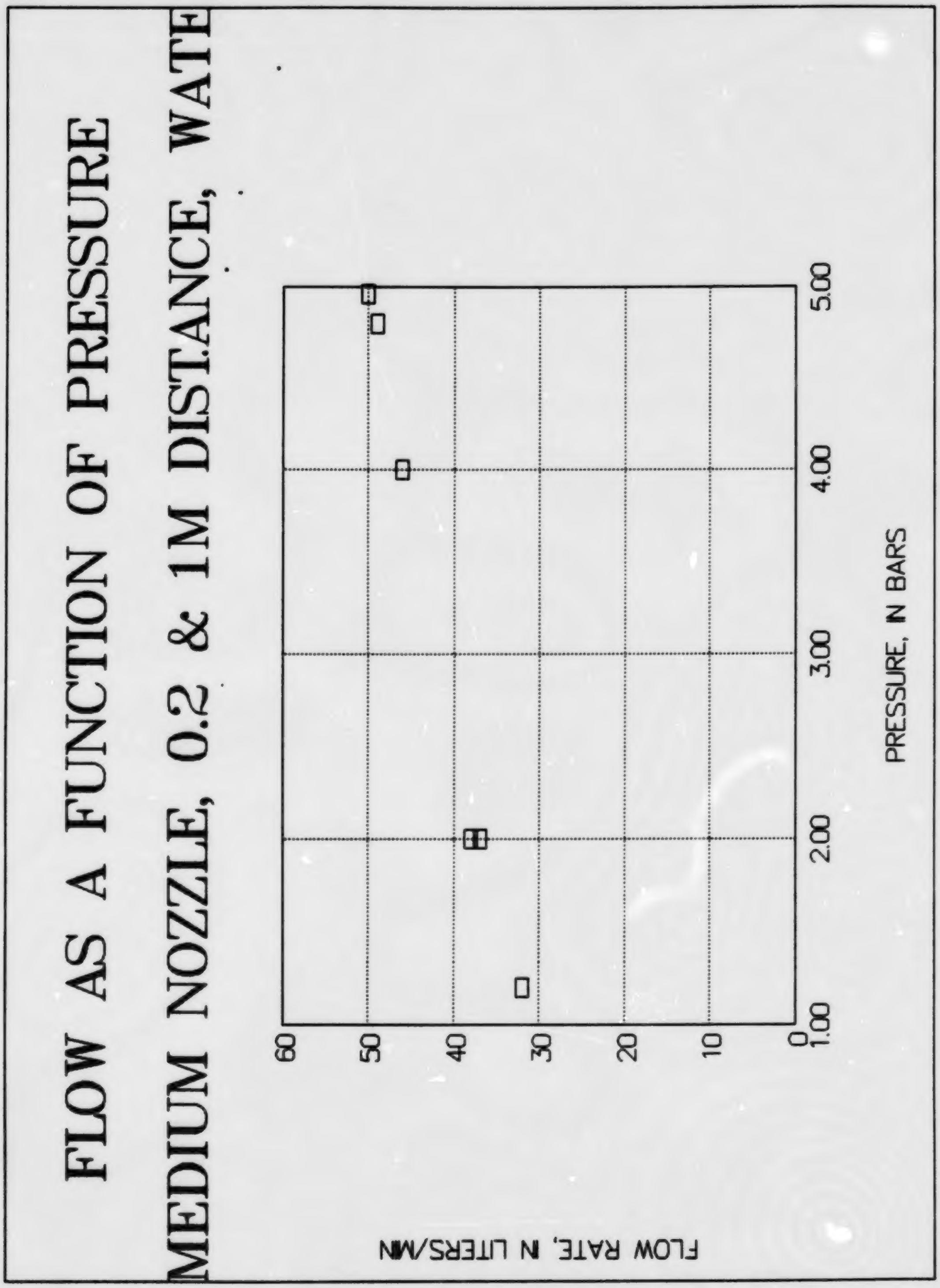
FLOW AS A FUNCTION OF PRESSURE

SMALL NOZZLE, 0.5 & 1 M DISTANCE, WATE



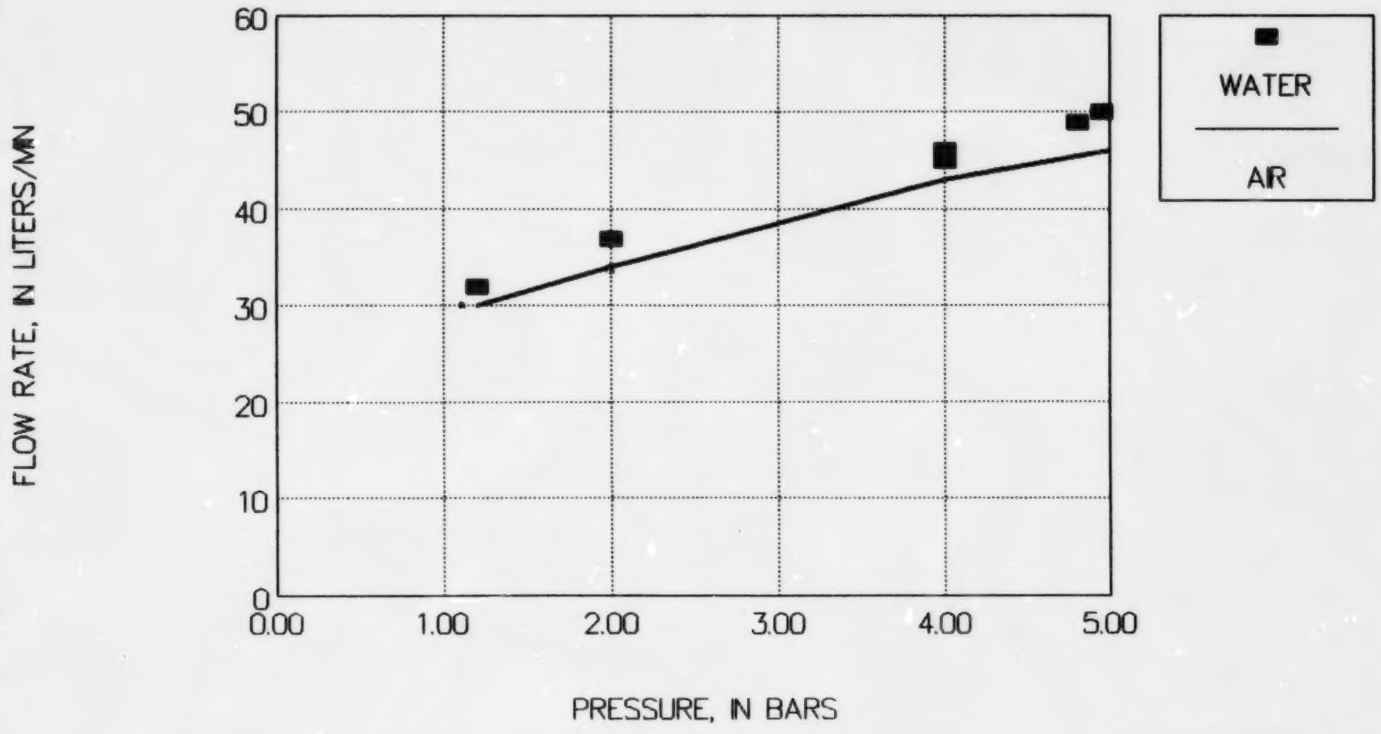


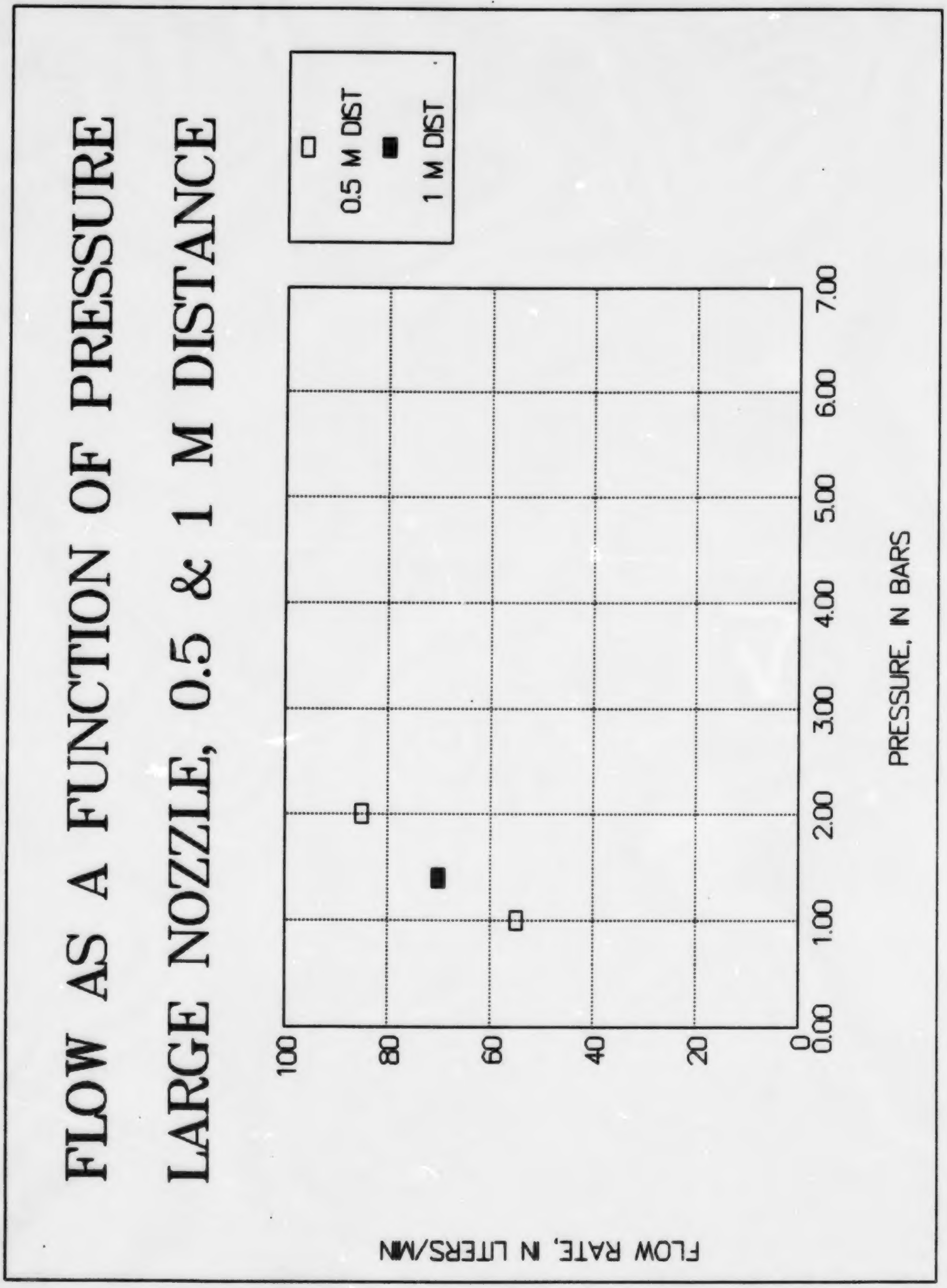
FLOW AS A FUNCTION OF PRESSURE
MEDIUM NOZZLE, 0.5M DISTANCE, IN WATER


FLOW AS A FUNCTION OF PRESSURE
MEDIUM NOZZLE, 0.2 & 1M DISTANCE, WATE

FLOW AS A FUNCTION OF PRESSURE

MED NOZZLE IN AIR AND WATER, 0.2 M DIS

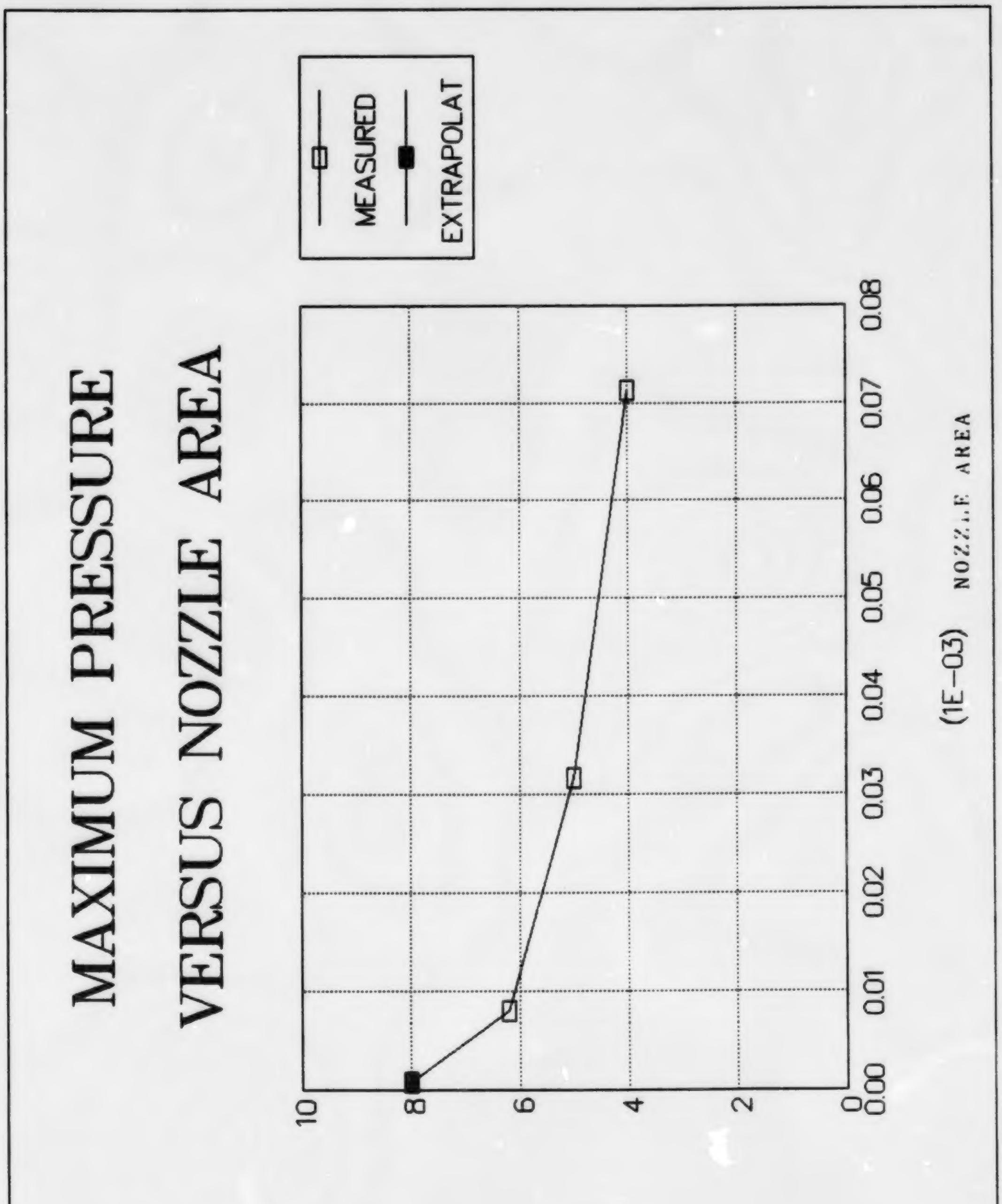




FLOW AS A FUNCTION OF PRESSURE

LARGE NOZZLE, 0.5 & 1 M DISTANCE

FIGURE 8.5.9


MAXIMUM PRESSURE
VERSUS NOZZLE AREA
MEASURED
EXTRAPOLAT
MAXIMUM PRESSURE, IN BARS
10
8
6
4
2
0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
(1E-03) NOZZLE AREA

## TABLE 8.5.4

### MAXIMUM FORCE AS A FUNCTION OF DISTANCE TO THE TARGET PLATE

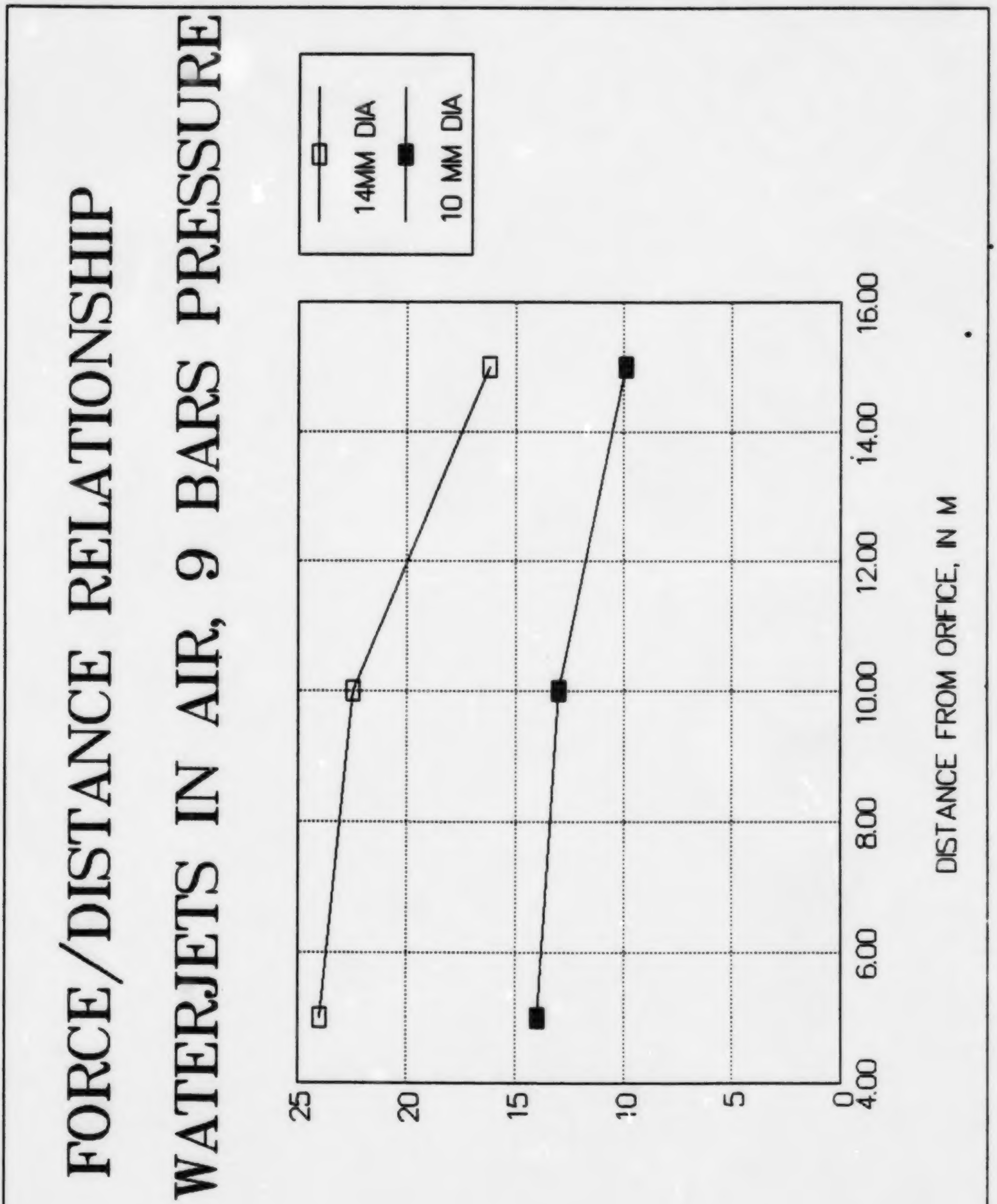
| NOZZLE AREA M^2 An | MAXIMUM PRESSURE BARS pmax | MAX FORCE* ACHIEVABLE | MAX FORCE, NEWTONS DISTANCE, IN M | | |
|---|---|---|---|---|---|
| | | 0 | 0.2 | 0.5 | 1 |
| 0.00E+00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7.92E-06 | 6.20 | 9.82 | | 7.92 | 5.65 |
| 3.17E-05 | 5.00 | 31.67 | 26.40 | 24.90 | 19.05 |
| 7.13E-05 | 4.00 | 57.00 | | 25.20 | 18.40 |

LARGE NOZZLE PRESSURE READING
EXTRAPOLATED TO 4 BARS
*CALCULATED USING THE FORMULA Fmax = 2* pmax * An

## TABLE 8.5.5

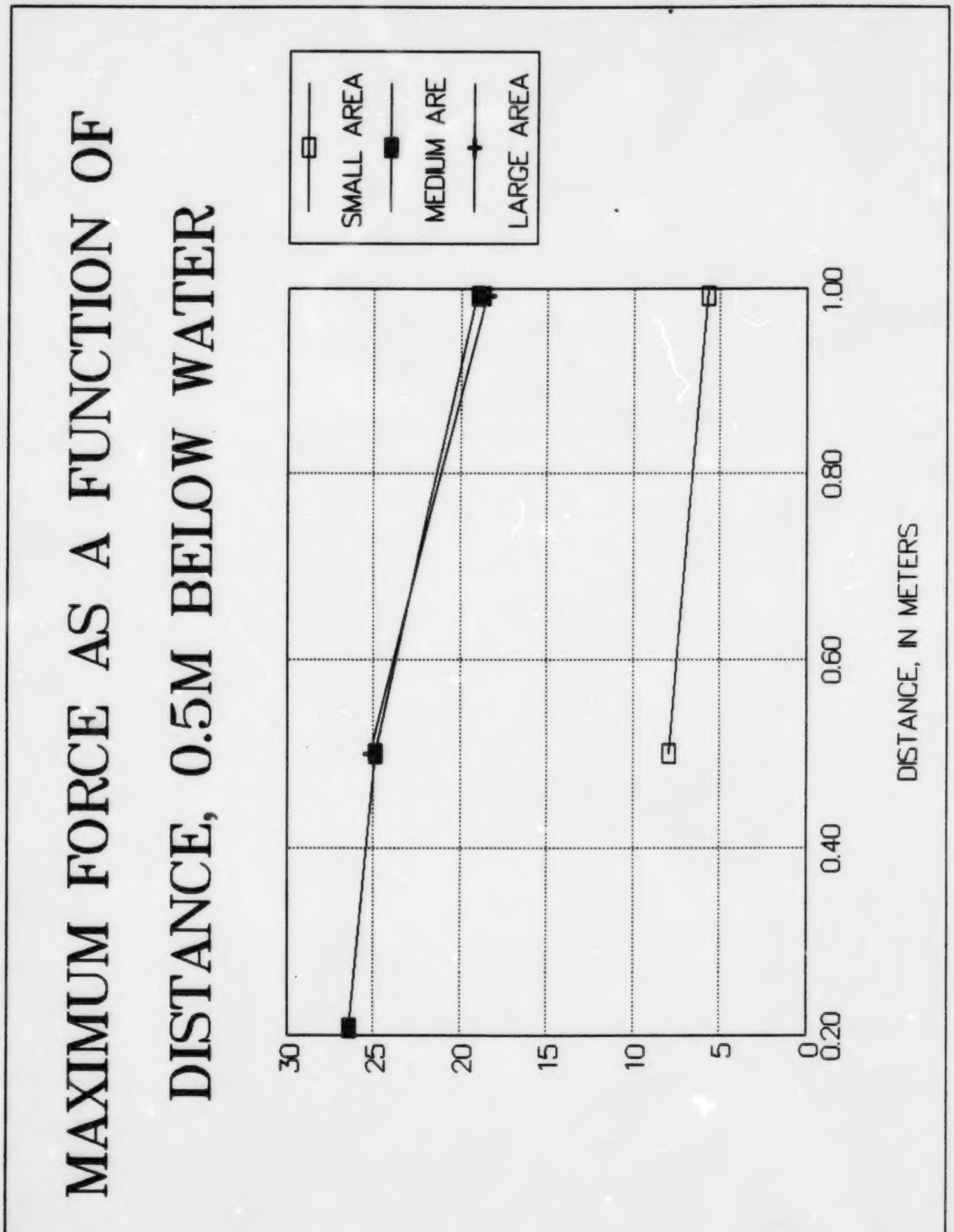
| PARAMETER | UNIT | MAXIMUM VALUES ACHIEVABLE VALUE | MEASURED |
|---|---|---|---|
| PRESSURE | PA | 800,000 | 62000 |
| FORCE | N | 57 | 26.4 |
| VELOCITY | M/S | 40.00 | 34 |
| FLOW RATE | M^3/S | 0.0029 | 0.0022 |

FIGURE 8.5.10



FORCE/DISTANCE RELATIONSHIP FOR WATERJETS IN AIR, 9 BARS PRESSURE

FIGURE 8.5.11



MAXIMUM FORCE AS A FUNCTION OF DISTANCE, 0.5M BELOW WATER

FIGURE 8.5.12

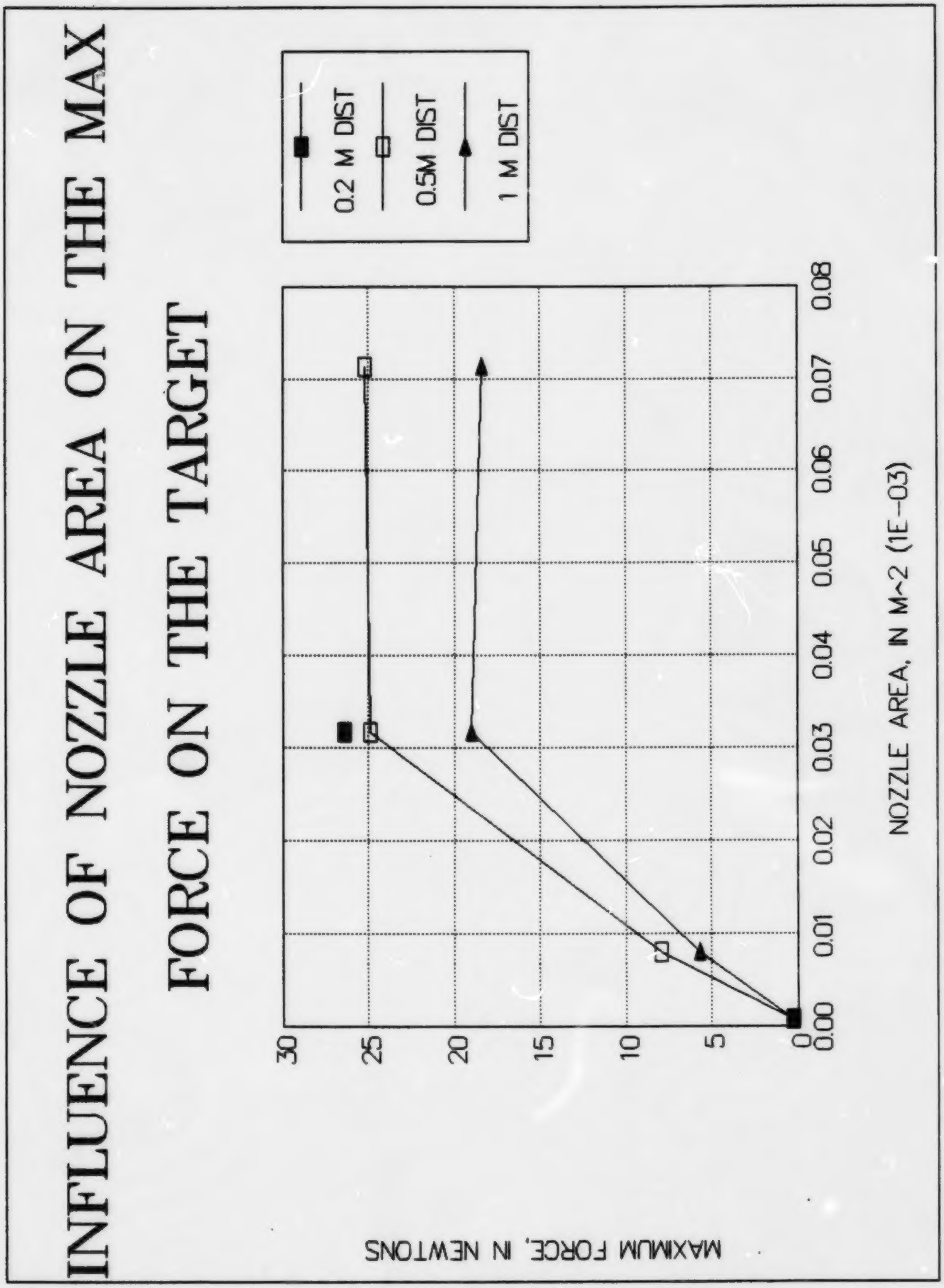
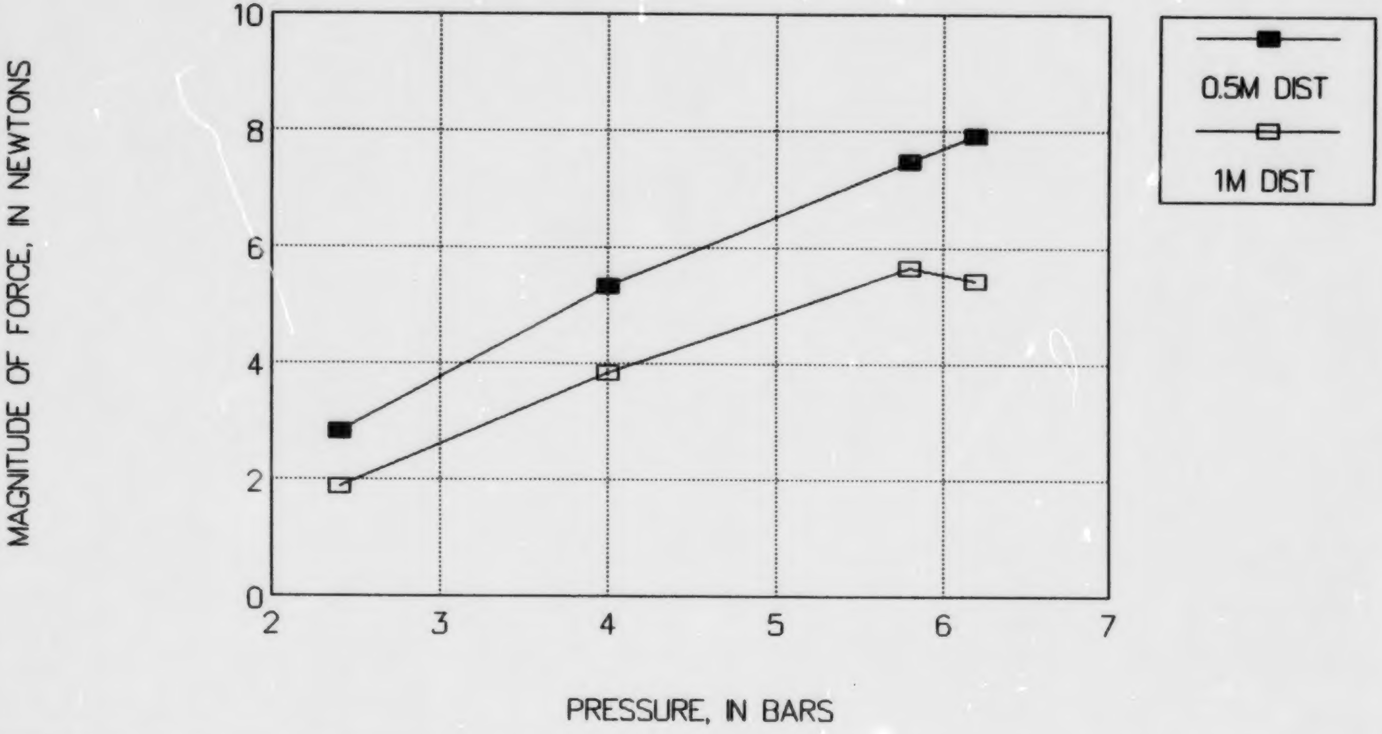
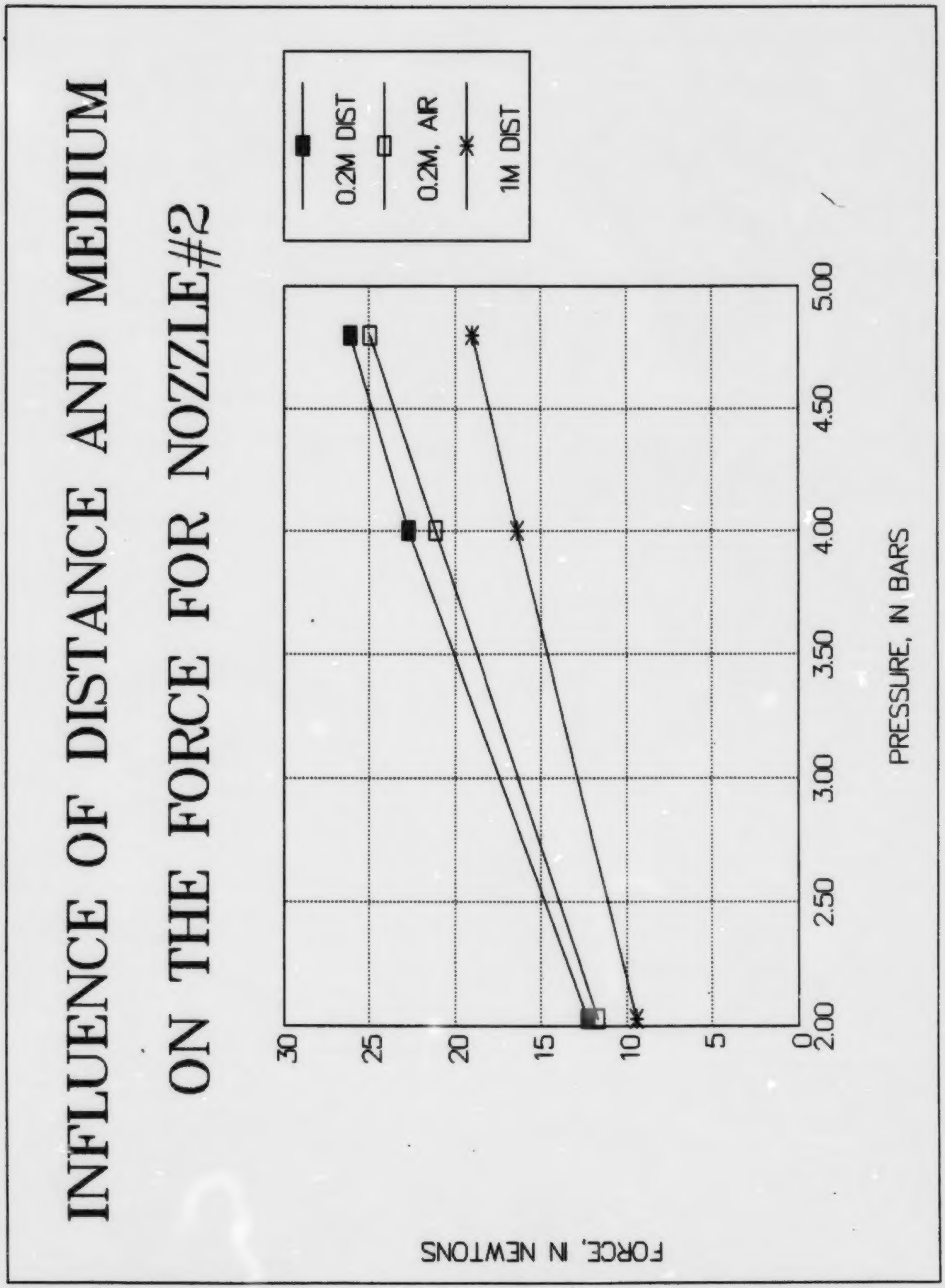

INFLUENCE OF NOZZLE AREA ON THE MAX
FORCE ON THE TARGET
0.2 M DIST
0.5M DIST
1 M DIST
MAXIMUM FORCE, IN NEWTONS
0
5
10
15
20
25
30
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
NOZZLE AREA, IN M^2 (1E-03)

FIGURE 8.5.13



INFLUENCE OF THE DISTANCE ON THE MAGNITUDE OF FORCE

FIGURE 8.5.14



INFLUENCE OF DISTANCE AND MEDIUM ON THE FORCE FOR NOZZLE#2

## TABLE 8.5.6

## FORCE ON THE TARGET AS A FUNCTION OF POWER

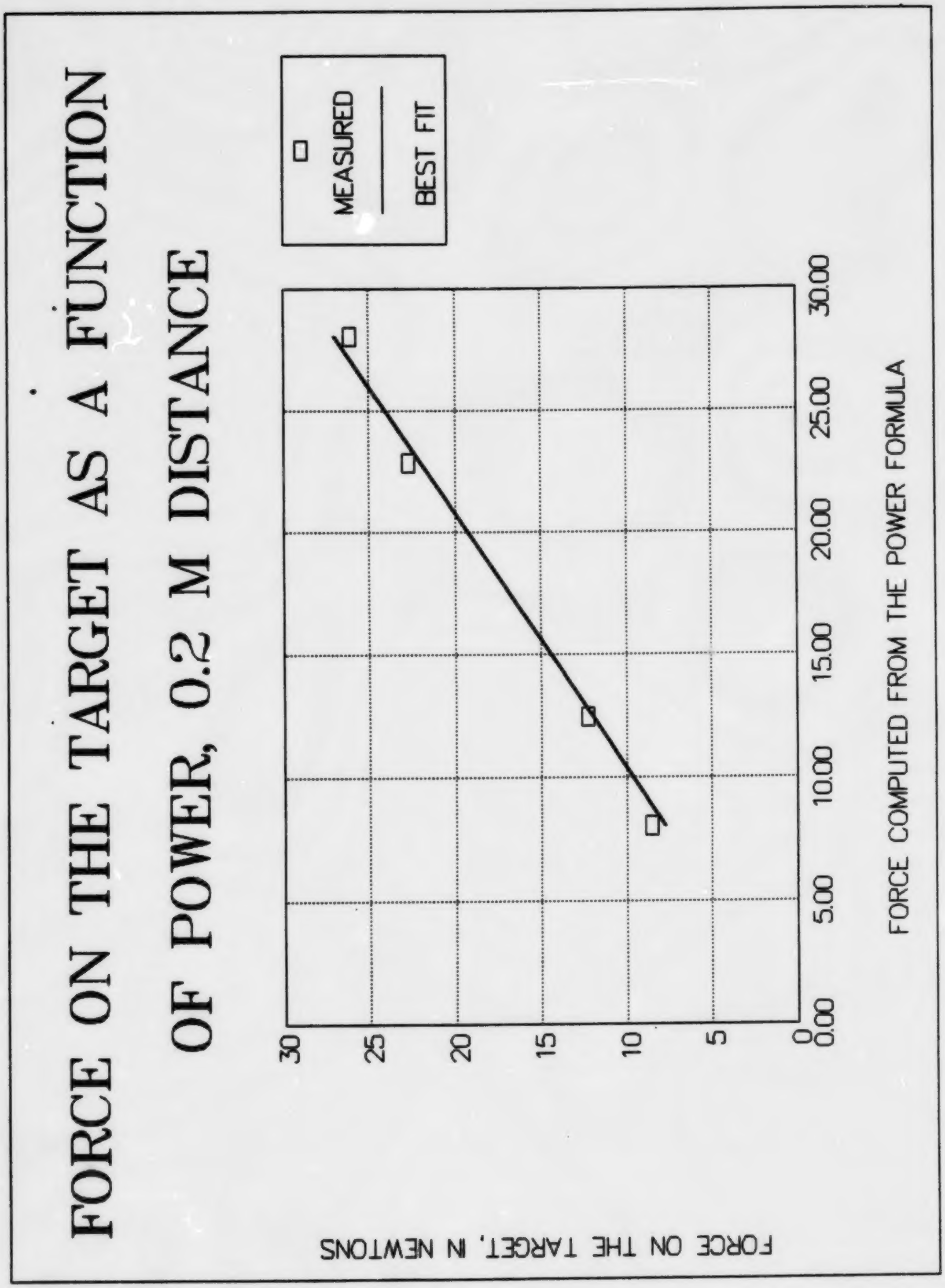
| POWER WATTS | MEASURED FORCE N | FORCE POWER FORMULA | MEASURED/ POWER LAW FORCE | REGRESSED FORCE N |
|---|---|---|---|---|
| 86.33 | 8.79 | 9.81 | 0.90 | 8.58 |
| 101.33 | 9.48 | 10.92 | 0.87 | 9.55 |
| 133.33 | 12.64 | 13.11 | 0.96 | 11.46 |
| 326.67 | 21.15 | 23.82 | 0.89 | 20.83 |
| 440.00 | 24.90 | 29.05 | 0.86 | 25.41 |
| 42.00 | 2.82 | 3.82 | 0.74 | 3.34 |
| 86.67 | 5.34 | 6.20 | 0.86 | 5.42 |
| 145.00 | 7.47 | 8.73 | 0.86 | 7.64 |
| 170.50 | 7.92 | 9.73 | 0.81 | 8.51 |
| | | | | |
| 33.33 | 1.87 | 3.28 | 0.57 | 2.29 |
| 86.67 | 3.83 | 6.20 | 0.62 | 4.33 |
| 162.00 | 5.65 | 9.40 | 0.60 | 6.56 |
| 167.40 | 5.43 | 9.61 | 0.57 | 6.71 |
| 126.67 | 9.44 | 12.67 | 0.75 | 8.84 |
| 306.67 | 16.41 | 22.84 | 0.72 | 15.95 |
| 392.00 | 19.05 | 26.90 | 0.71 | 18.78 |
| | | | | |
| 64.00 | 8.50 | 8.04 | 1.06 | 7.75 |
| 123.33 | 12.30 | 12.44 | 0.99 | 12.00 |
| 306.67 | 22.70 | 22.84 | 0.99 | 22.02 |
| 416.67 | 26.10 | 28.02 | 0.93 | 27.01 |

| | |
|---|---|
| **AVG** | 185.86 |
| **MAX** | 440 |

## TABLE 8.5.7

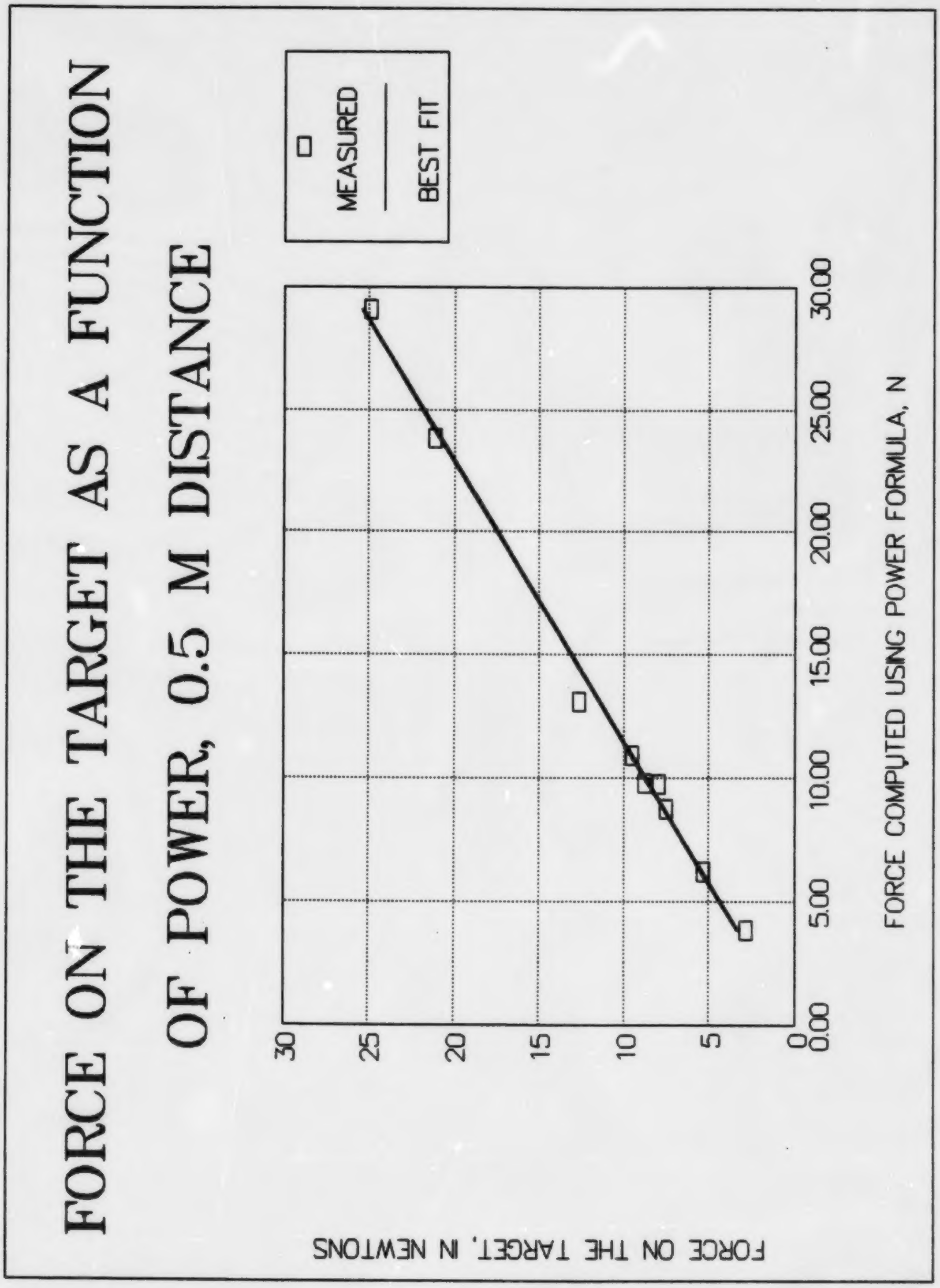
## REGRESSION RESULTS OF FORCE/DISTANCE RELATIONSHIP

```
=====================================
         Regression Output:0.5M DIST
Constant                           0
Std Err of Y Est            0.552933
R Squared                   0.994269
No. of Observations                9
Degrees of Freedom                 8

X Coefficient(s)  0.874482
Std Err of Coef.  0.012294


=====================================

         Regression Output:1.0M DIST
Constant                           0
Std Err of Y Est            0.767747
R Squared                    0.98626
No. of Observations                7
Degrees of Freedom                 6

X Coefficient(s)  0.698212
Std Err of Coef.  0.018984

=====================================
         Regression Output:0.2M DIST
Constant                           0
Std Err of Y Est            0.806819
R Squared                   0.990656
No. of Observations                4
Degrees of Freedom                 3

X Coefficient(s)  0.963993
Std Err of Coef.  0.020654

=====================================
```



FORCE ON THE TARGET AS A FUNCTION OF POWER, 0.2 M DISTANCE

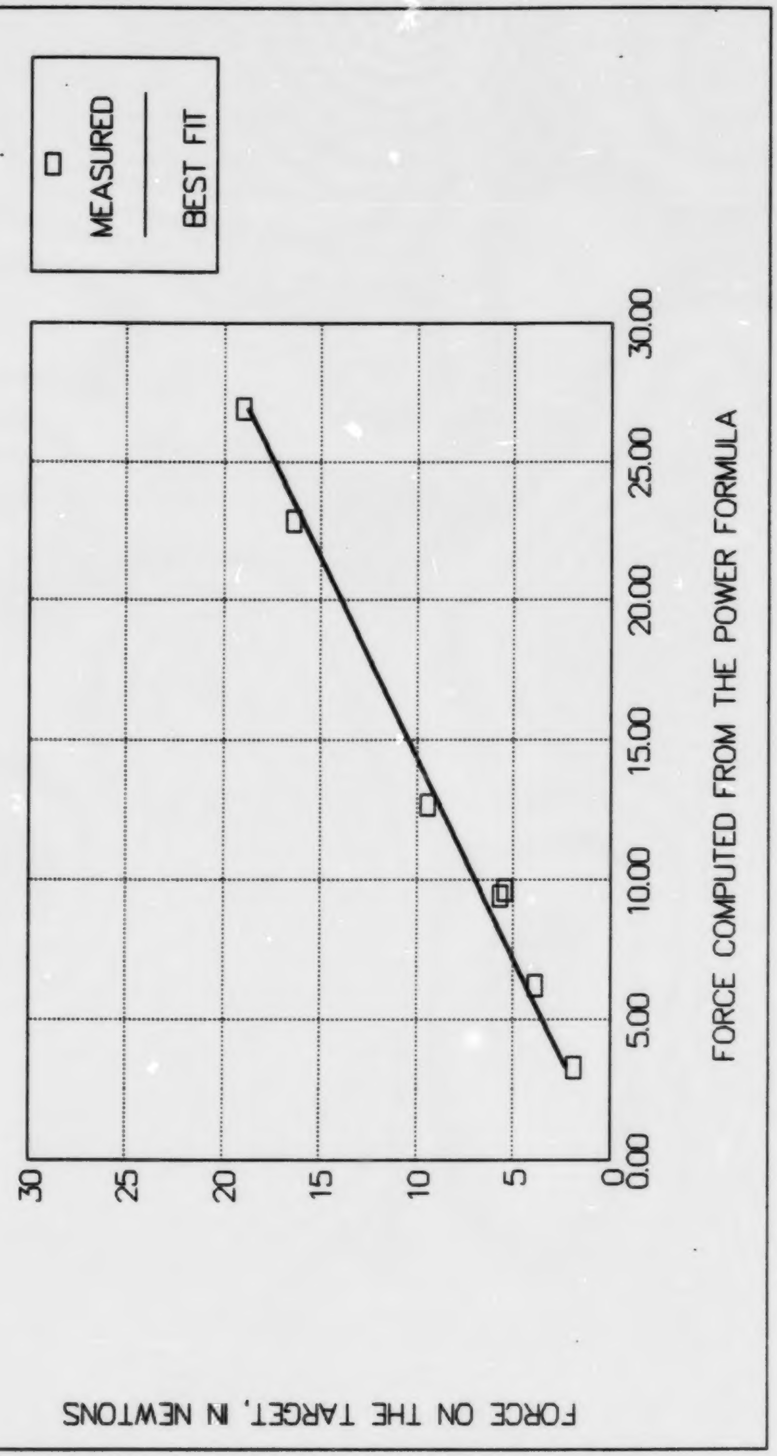
FIGURE 8.5.16



FORCE ON THE TARGET AS A FUNCTION OF POWER, 0.5 M DISTANCE

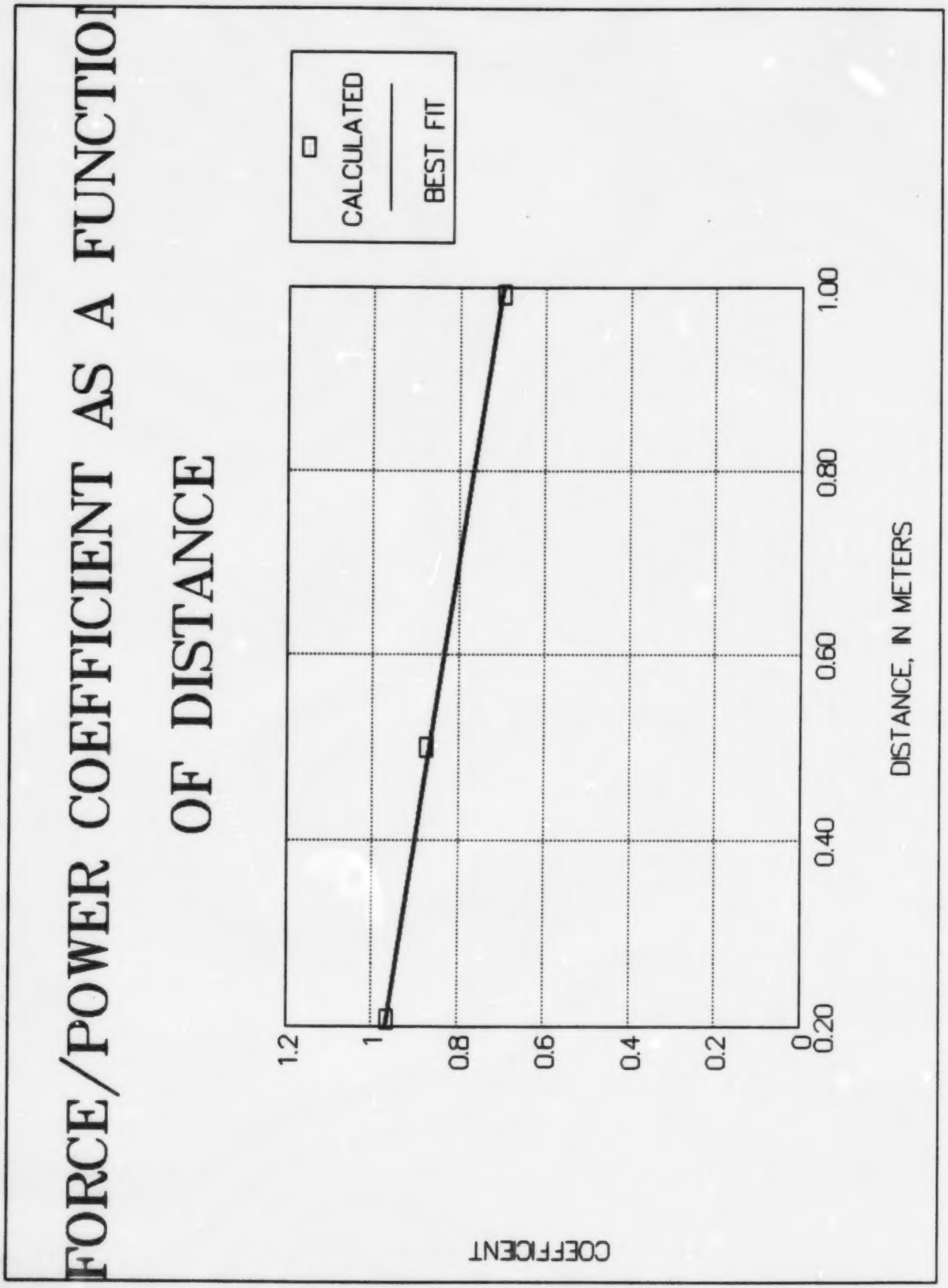
FIGURE 8.5.17

FORCE ON THE TARGET AS A FUNCTION OF POWER, 1.0 M DISTANCE



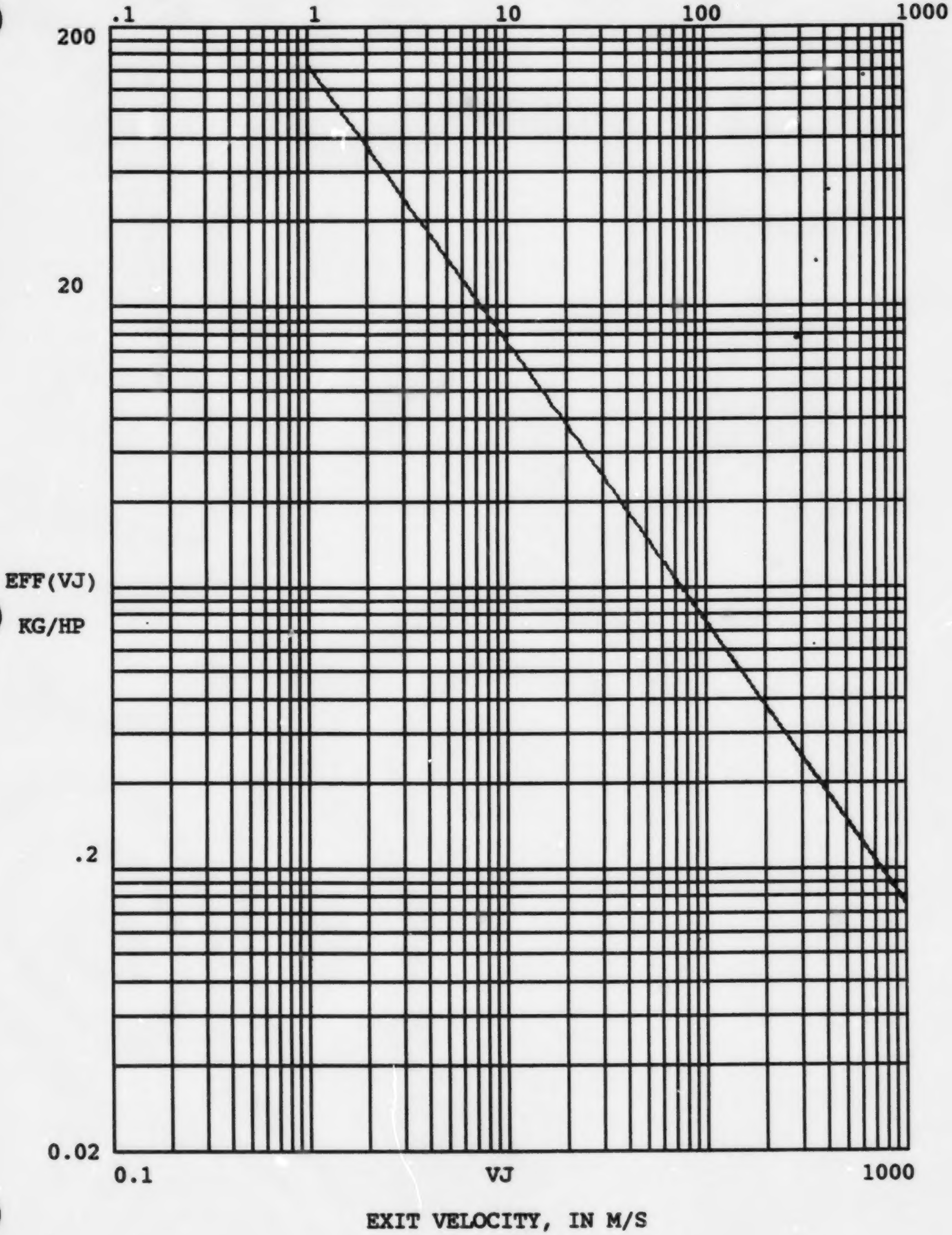
## TABLE 8.5.9

```
REGRESSION RESULTS OF FORCE/POWER
         AND
DISTANCE RELATIONSHIP
=====================================
DISTANCE DIST^1.  COEFF    REGRESSED
    M      M^1.              COEFF
     0.2       0.2   0.964  0.968139
     0.5       0.5   0.874  0.867849
       1         1   0.698  0.700699

=========================================


         Regression Output:
Constant                    1.034999
Std Err of Y Est            0.008208
R Squared                   0.998158
No. of Observations                3
Degrees of Freedom                 1

X Coefficient(s)   -0.3343
Std Err of Coef.  0.014361

=======================================
```


FORCE/POWER COEFFICIENT AS A FUNCTIO
OF DISTANCE
CALCULATED
BEST FIT
COEFFICIENT
1.2
1
0.8
0.6
0.4
0.2
0
0.20
0.40
0.60
0.80
1.00
DISTANCE, IN METERS

## FIGURE 8.5.19

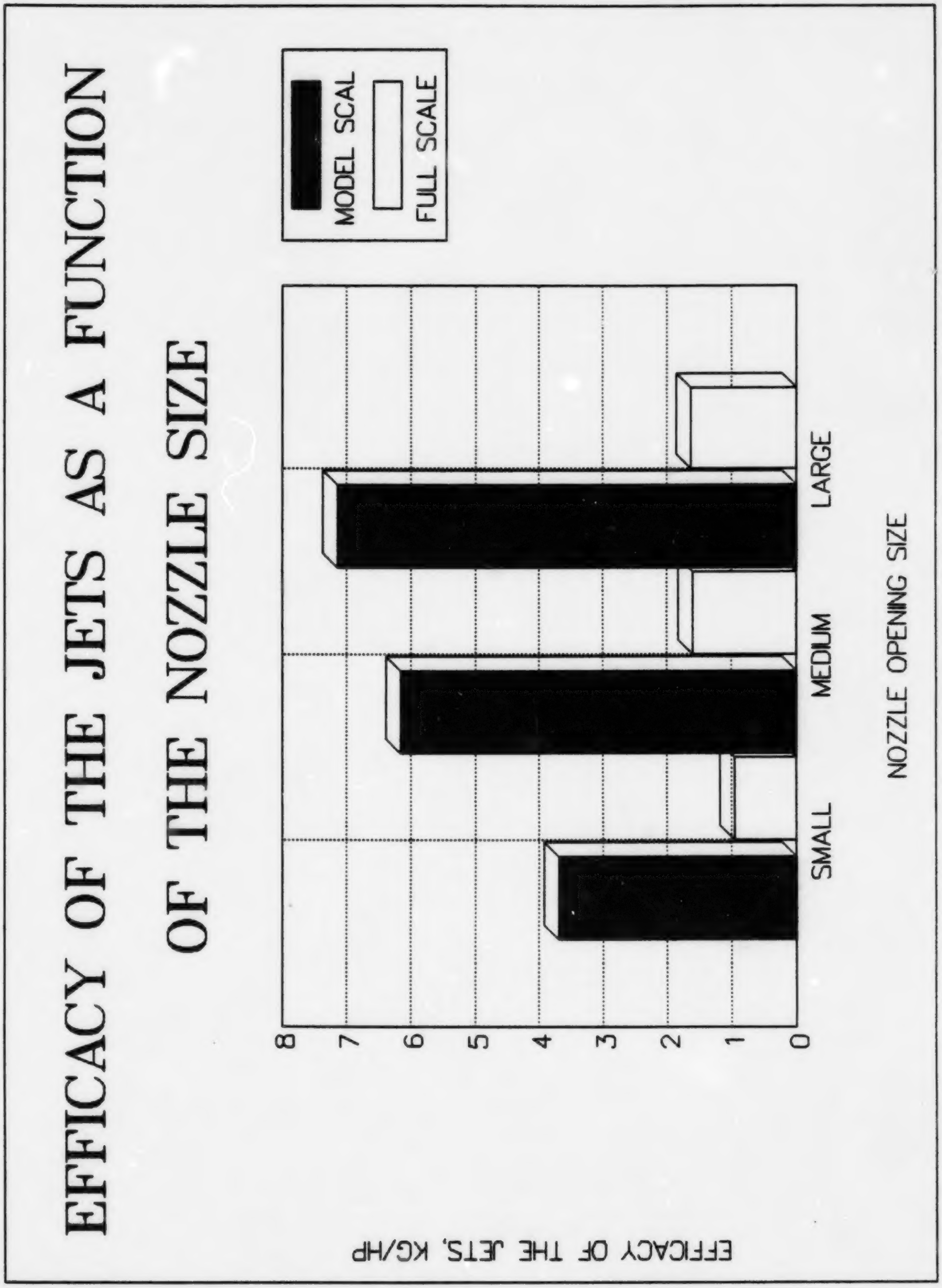
### WATER JET EFFICACY AS A FUNCTION OF EXIT VELOCITY



## TABLE 8.5.11

JET EFFICACY KG/HP

| | MODEL SCALE NOZZLE ORIFICE AREA SMALL | MEDIUM | LARGE | IDEAL EFFICACY | ACTUAL/ IDEAL | FULL SCALE 0.258 PREDICTION SMALL | MEDIUM | LARGE |
|---|---|---|---|---|---|---|---|---|
| | | 7.64 | | 7.70 | 0.99 | | 1.97 | |
| | | 7.02 | | 7.50 | 0.94 | | 1.81 | |
| | | 7.11 | | 7.13 | 1.00 | | 1.84 | |
| | | 4.86 | | 5.82 | 0.83 | | 1.25 | |
| | | 4.24 | | 5.18 | 0.82 | | 1.10 | |
| | | | 6.30 | 11.66 | 0.54 | | | 1.63 |
| | | | 6.67 | 7.54 | 0.88 | | | |
| | 5.04 | | | 6.79 | 0.74 | 1.30 | | |
| | 4.62 | | | 5.48 | 0.84 | 1.19 | | |
| | 3.86 | | | 4.75 | 0.81 | 1.00 | | |
| | 3.48 | | | 4.32 | 0.81 | 0.90 | | |
| | 4.21 | | | 7.13 | 0.59 | 1.09 | | |
| | 3.31 | | | 5.48 | 0.60 | 0.86 | | |
| | 2.62 | | | 4.40 | 0.59 | 0.68 | | |
| | 2.43 | | | 4.40 | 0.55 | 0.63 | | |
| | | | 8.45 | 9.16 | 0.92 | | | |
| | | 5.59 | | 7.50 | 0.75 | | 1.44 | |
| | | 4.01 | | 6.20 | 0.65 | | 1.04 | |
| | | 3.64 | | 5.82 | 0.63 | | 0.94 | |
| | | 9.96 | | 8.91 | 1.12 | | 2.57 | |
| | | 7.48 | | 7.70 | 0.97 | | 1.93 | |
| | | 5.55 | | 6.20 | 0.90 | | 1.43 | |
| | | 4.70 | | 5.70 | 0.82 | | 1.21 | |
| | | 5.10 | | 6.33 | 0.81 | | 1.32 | |
| | | 5.05 | | 5.82 | 0.87 | | 1.30 | |
| | | 11.90 | | 9.50 | 1.25 | | 3.07 | |
| | | 7.75 | | 8.38 | 0.92 | | 2.00 | |
| | | 5.53 | | 6.63 | 0.83 | | 1.43 | |
| | | 5.08 | | 6.20 | 0.82 | | 1.31 | |
| MAX | 5.04 | 11.90 | 8.45 | | | 1.30 | 3.07 | 1.63 |
| AVG | 3.70 | 6.15 | 7.14 | | | 0.95 | 1.59 | 1.63 |
| MIN | 2.43 | 3.64 | 6.30 | | | 0.63 | 0.94 | 1.63 |



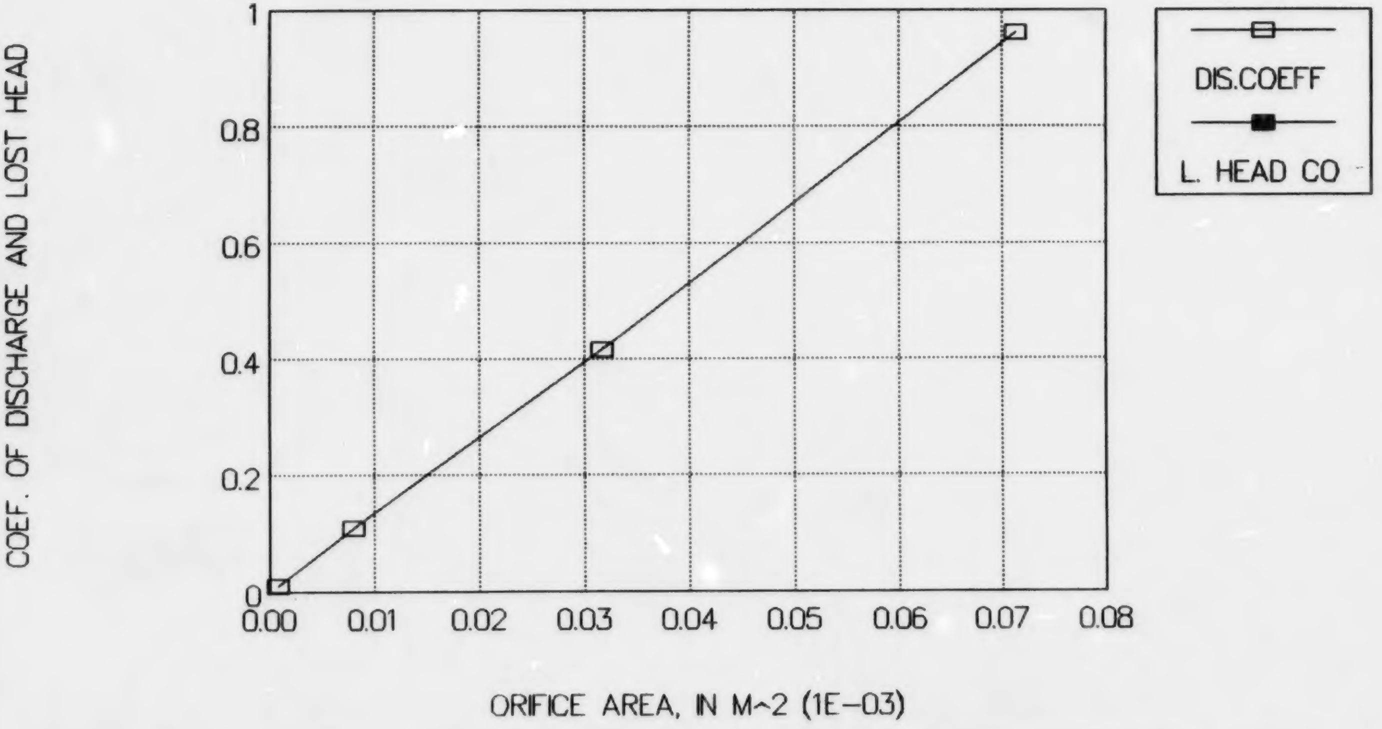
EFFICACY OF THE JETS AS A FUNCTION OF THE NOZZLE SIZE

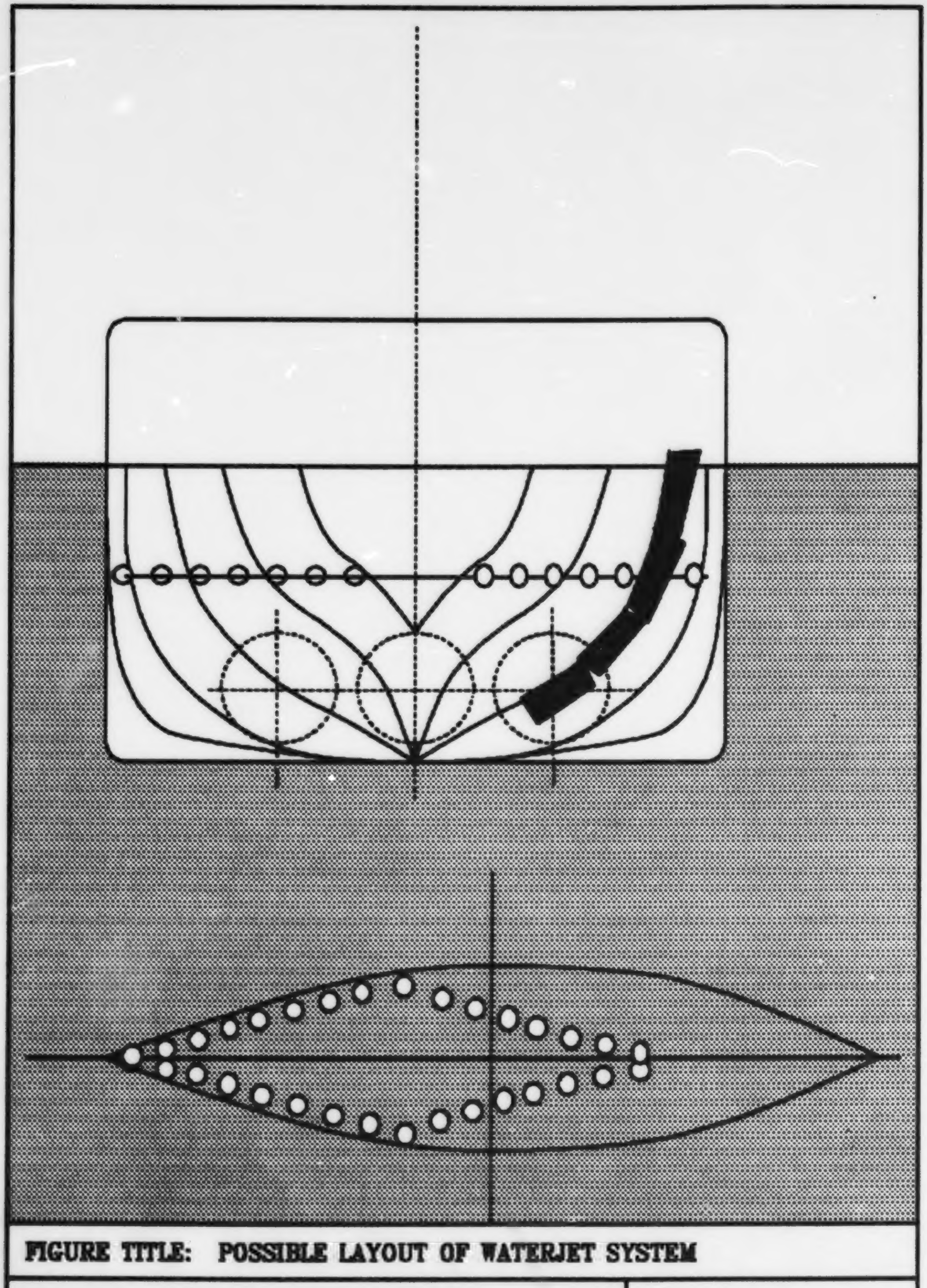
## TABLE 8.5.12

### HYDRAULIC EFFICIENCY OF THE REDUCTOR/NOZZLE SYSTEM

| GAUGE VELOCITY M/S | COEFFICIENT OF DISCHARGE AND VELOCITY | | | POWER LOSS FACTOR (p/ro*V^2/2) | | |
|---|---|---|---|---|---|---|
| | SMALL | MEDIUM | LARGE | SMALL | MEDIUM | LARGE |
| 8.65 | | 0.52 | | | 0.74 | |
| 8.89 | | 0.50 | | | 0.80 | |
| 9.36 | | 0.47 | | | 0.90 | |
| 11.46 | | 0.41 | | | 1.20 | |
| 12.86 | | 0.42 | | | 1.15 | |
| 12.86 | | | 0.91 | | | 1.21 |
| 19.88 | | | 0.99 | | | 1.01 |
| 2.46 | 0.11 | | | 0.98 | | |
| 3.04 | 0.11 | | | 1.07 | | |
| 3.51 | 0.10 | | | 1.16 | | |
| 3.86 | 0.11 | | | 1.03 | | |
| 2.34 | 0.12 | | | 0.90 | | |
| 3.04 | 0.11 | | | 1.07 | | |
| 3.79 | 0.11 | | | 1.03 | | |
| 3.79 | 0.11 | | | 1.07 | | |
| 16.37 | | | 0.98 | | | 1.04 |
| 8.89 | | 0.44 | | | 1.00 | |
| 10.76 | | 0.38 | | | 1.37 | |
| 11.46 | | 0.37 | | | 1.44 | |
| 7.48 | | 0.48 | | | 0.85 | |
| 8.65 | | 0.43 | | | 1.05 | |
| 10.76 | | 0.38 | | | 1.37 | |
| 11.69 | | 0.37 | | | 1.44 | |
| 10.53 | | 0.37 | | | 1.43 | |
| 11.46 | | 0.37 | | | 1.44 | |
| 7.02 | | 0.47 | | | 0.88 | |
| 7.95 | | 0.40 | | | 1.25 | |
| 10.06 | | 0.36 | | | 1.56 | |
| 10.76 | | 0.35 | | | 1.64 | |
| MIN | 0.10 | 0.35 | 0.91 | 0.90 | 0.74 | 1.01 |
| AVG | 0.11 | 0.42 | 0.96 | 1.04 | 1.20 | 1.09 |
| MAX | 0.12 | 0.50 | 0.99 | 1.16 | 1.64 | 1.21 |

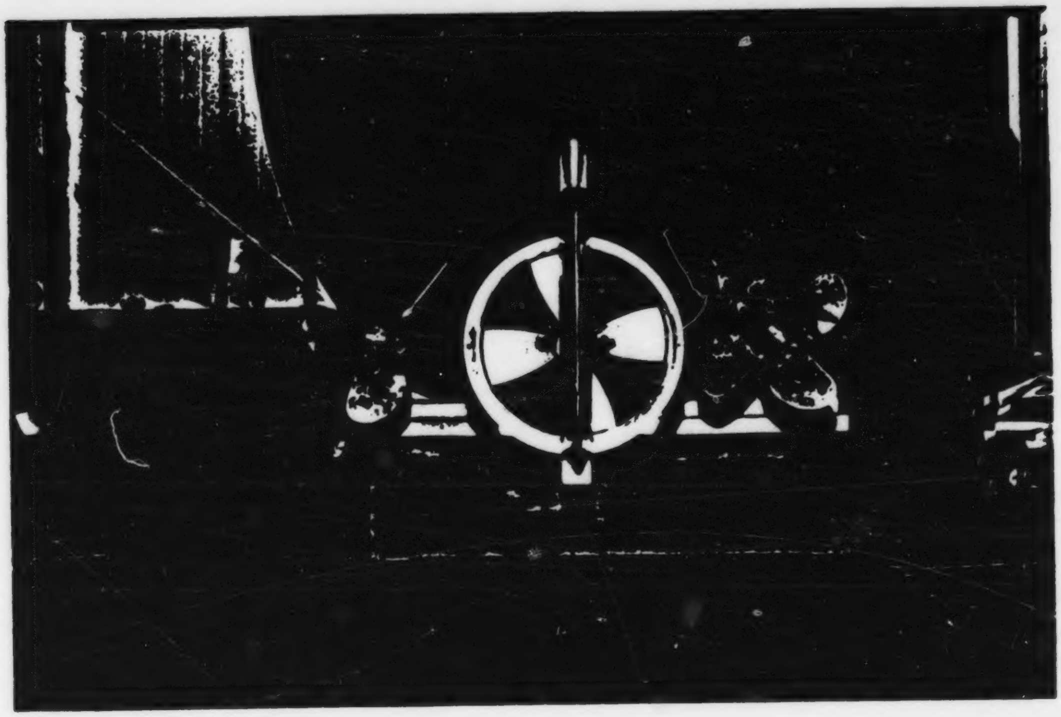
## HYDRAULIC EFFICIENCY OF THE NOZZLES AS A FUNCTION OF THE ORIFICE AREA





|  |  |  |  |
|---|---|---|---|
| **FIGURE TITLE: POSSIBLE LAYOUT OF WATERJET SYSTEM** | | | |
| **PROJECT NAME: ICE BLOCKAGE AND FLOW INVEST'N** | | | **PROJECT NR:** |
| **DRAWN BY: VL** | **CHK'D BY: VL** | **SCALE: NONE** | **FIGURE NR:** |

**ARAD**



# 9. OVERLOAD TESTS RESULTS

## 9.1 Objectives

*These tests were conducted in order to establish the reference characteristics of the propeller/ nozzle system before testing the model in ice and in simulated blockage conditions.*

## 9.2 Tests setup

*Model of the ship was attached to the carriage, but free to pitch. Three shafts were instrumented for RPS. In addition, the centerline shaft was instrumented for torque and thrust. Nozzle support was instrumented in a fashion permitting the estimation of the nozzle thrust, as well as the vertical and horizontal location of the thrust vector.*
*The carriage was instrumented for speed measurements and tow rope pull.*
*Details of the test setup are contained in the Appendix L.*

## 9.3 Method used

*Initial propulsion parameters selected for the model were arrived at as follows:*

*Delivered maximum power to the centerline shaft was set, after consultation with TDC/CCG, set at 7,000 HP. The ship in ice operates normally at somewhat reduced power, as a safety precaution and fuel saving measure. Reference 1 based on the actual full scale measurements of the power utilization of the ship demonstrates that the ship was using* ***less than 50%*** *of the full power* ***in 9/10 ice cover*** *fields.*

*As the tests in ice were intended to simulate the broken ice field condition, powers less than maximum were used. Extrapolation to the full power condition is straight forward.*

*The parameter influencing the ice ingestion into the nozzle is the thrust of the system, as it relates to the "suction power." The* ***thrust identity*** *of the nozzle propeller system was adhered to throughout the tests. As the propeller and nozzle supplied were not of the standard design,their thrust calibration was necessary.*

*This was accomplished as follows:*

*For a series of 9 icebreaking ships outfitted with nozzles, the total bollard thrust/power relationship were obtained. This is shown in Figure 9.1. The regression of data gave the following relationship ( Table 9.1 gives the details of the regression):*

*Thrust (prop + nozzle), tonnes = 0.0114 * HP..........9.1*

*For the set power of 7,000 HP the corresponding thrust was found to be 80 tonnes (11.4 kG/HP). This thrust of the nozzle/ propeller system was set as a baseline, for which the RPS of the propeller were found. Using the bollard runs, the following relationship was obtained:*

*Thrust (prop + nozzle), Nm = -87.14 + RPS *39.71.......9.2*

*Figure 9.2 and Table 9.2 show the relationships. From the above equation, the model scale RPS giving the desired total thrust of the centerline propeller and nozzle of 232.5 N was found to be 8 RPS. This RPS was used as a base. The corresponding base line torque was found to be 7.84 Nm. Table 9.3 lists the baseline parameters:*

*TABLE 9.3*

*SUMMARY OF BASE LINE PARAMETERS*
*thrust identity, centerline shaft, bollard condition*

| | model | full scale |
|---|---|---|
| ***Thrust of the system*** | ***232.50 N*** | ***80 tonnes*** |
| *Corresponding RPS* | *8.00 1/s* | *124 RPM* |
| *Corresponding torque* | *7.84 Nm* | *396.9 kNm* |
| *Corresponding power* | *394.00 Watts* | *7000 HP* |

*Due to the complications with separate wing propeller controls, they were operated at the same RPS as the center one.*

*Test progressed as follows:*

*After initial acceleration of the carriage, the steady state of towing resulted. The power on the shafts was brought up stepwise from zero to near maximum. The constant signal windows were kept in excess of 10 sec, for each power level.*

*Figure 9.3 shows the typical set of recordings.*
*Due to the scatter of data , some points were "smoothed out".*

## 9.4 Results of overload tests.

*Table 9.4 summarizes the results of the overload tests. The following speeds were tested:*

| *ahead* *kn* | *astern* *kn* |
|---|---|
| *Bollard* | *Bollard* |
| *5* | *2* |
| *10* | *4* |
| *15* | *6* |

*Figures 9.4 to 9.11 show the dependence of the*

*nozzle thrust,*
*propeller thrust,*
*total thrust and*
*torque*

*of the centerline nozzle/propeller system on the RPS and the speed of towing.*

*Following are the noteworthy points:*

1. *At bollard ahead condition, nozzle delivers more thrust than the propeller, by some 35%.*

2. *Nozzle thrust follows the same RPS trend as the propeller thrust.*

3. *For the same RPS, torque in astern bollard condition is higher by less than 10% than that in bollard ahead. The thrust astern is however equal to the thrust of the system ahead.*

4. *Fixed propeller thrust astern is higher than the nozzle thrust astern.*

*The contribution of the centerline nozzle/propeller system to the tow rope pull is shown in Figure 9.12. The centerline system contributes more than 50% of the total thrust at reduced powers, and more than 33% at high power.*

*The location of the nozzle thrust vector in bollard condition is shown in Figure 9.13. The loci are strongly dependent on RPS. The vertical relative radius Z/R varies from -0.2 to 0.05 while the horizontal location oscillates around -0.05 relative radius. (positive is up and to the starboard looking forward). Loci for the 5 knots ahead is shown in Figure 9.14. It is clear that the* *higher power developed stabilizes the locus of the thrust near the center of the nozzle.*

### *9.5 Efficacy of the system*

*Efficacy of the propeller and nozzle is defined as Thrust/Power delivered to the system. Units are kG/HP. Table 9.5 summarizes the computations and Figure 9.15 shows the efficacy of the system extrapolated to the full scale. The efficacy at partial loadings is very good, and at full power setting it is*

*11.5 kG/HP,*

*which is much higher than for the unshrouded propellers.*

*Other efficacy indicators, like the tow pull/power delivered and the tow pull/ thrust of the centerline system are shown in Figures 9.16 and 9.17 at bollard ahead and bollard astern condition, respectively.*

### *9.6 Thrust deduction factor*

*Table 9.6 and Figure 9.18 summarize the computations of the thrust deduction factor (TDF) in* ***bollard ahead and astern*** *conditions, based on the data obtained in this and other test series. As the wing propellers were not instrumented, the tests with the wing propellers stopped served as a data base.*

*The following observations are made:*

*For the bollard ahead, the average TDF is:*

***0.23**, for the power level of 82% of MCR.*

*This is more than twice the value reported from the LSSL full scale trials (t = 0.1), without the nozzle and with the wing propellers operating. It should be noted that the nozzle increases the TDF because large part of it operates in the close proximity to the hull (the upper half).*
*Further, the stopped wing propellers present an obstacle to the water inflow into the center one, thus creating an additional drag, hence the additional TDF.*

*In the bollard astern condition, the mean value of the TDF is:*

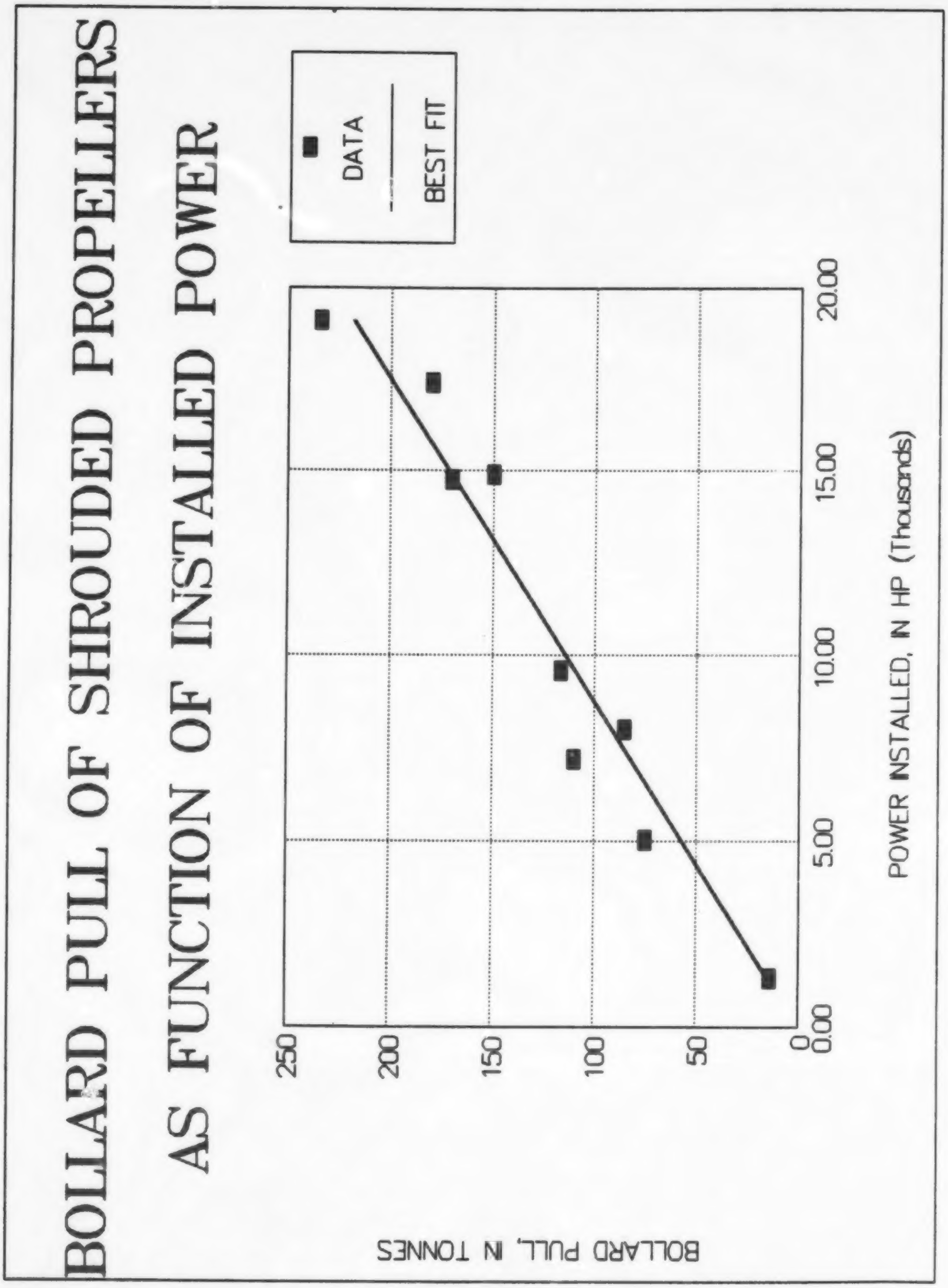
***0.32**, for the power level of 124% of MCR.*

*This is, as expected, 39% higher than the TDF in the ahead bollard condition.*

## *9.7 Conclusions from this test series*

1. *The centerline nozzle and propeller develop **11.4 kG/HP** (full scale) which is **more than 35% higher** than the corresponding open propeller, in bollard condition.*
2. *Thrust astern in the bollard astern condition is approximately equal to the thrust ahead of the system, in ahead bollard condition, for the same RPS.*
3. *High astern thrust of the system (**70% of the bollard ahead**) is maintained even at **6 knots astern** speed.*
4. *The above findings confirm fully the results of the investigations contained in the Reference 1.*
5. *Nozzle develops more thrust than the propeller at bollard ahead condition.*
6. *The location of the nozzle thrust vector changes with the change of nozzle load, especially the vertical one.*
7. *The location of the thrust vector is predominantly below the nozzle axis.*
8. *Centerline nozzle/propeller system delivers **more than 1/3** of the total three shafts thrust, for the constant RPS, for all conditions tested (from 40% to 60% of the total).*
9. *The thrust deduction factor is **0.23** for the centerline nozzle and propeller system, in the ahead bollard condition and with the wing propellers stopped.*
10. *For the astern bollard condition, the thrust deduction factor is **0.32**.*

Figure 9.1


BOLLARD PULL OF SHROUDED PROPELLERS AS FUNCTION OF INSTALLED POWER

## TABLE 9.1

## BOLLARD PULL/INSTALLED POWER

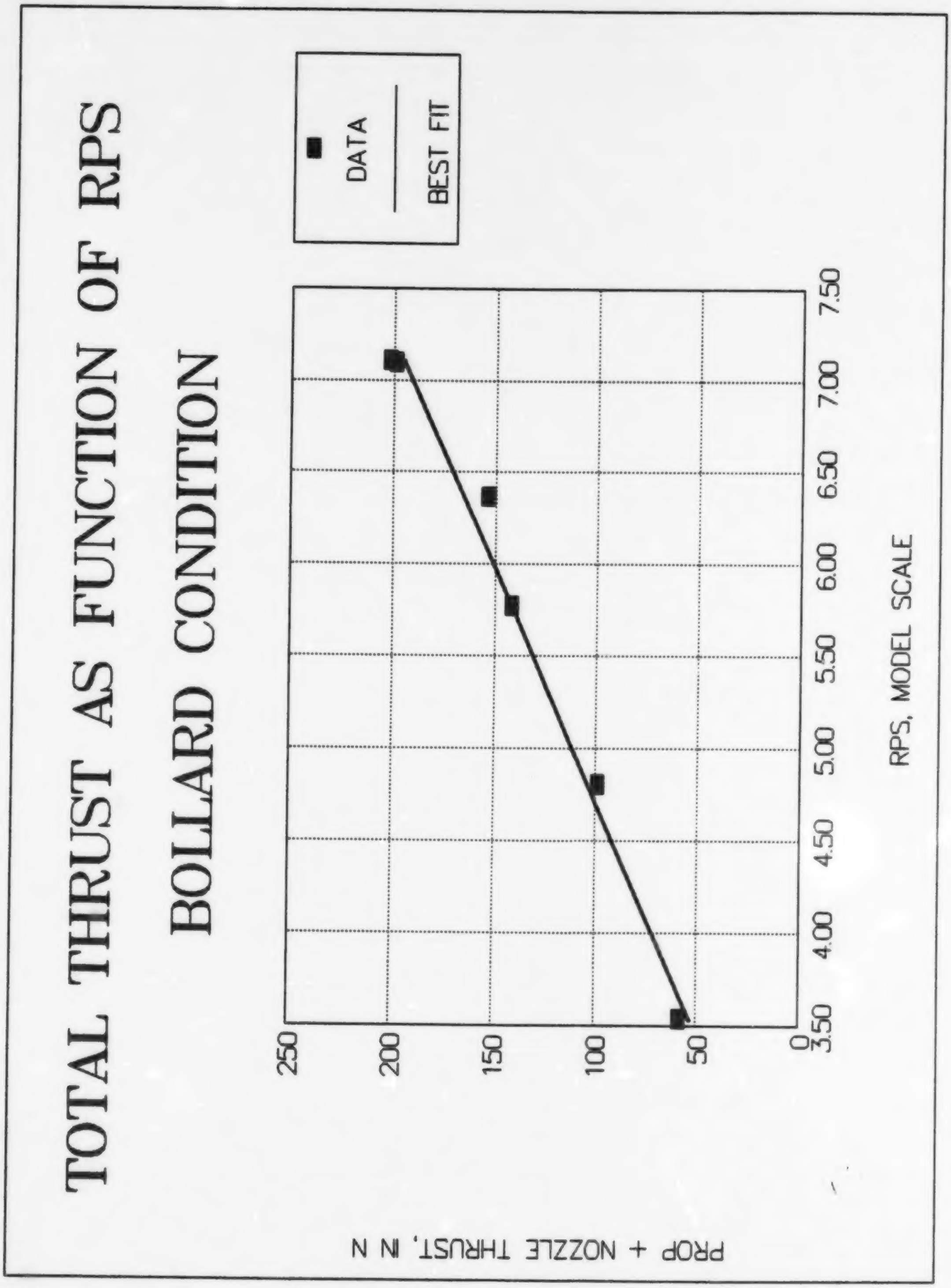
## REGRESSION DATA

```
      Regression Output:
Constant                               0.000
Std Err of Y Est                      16.536
R Squared                              0.936
No. of Observations                    9.000
Degrees of Freedom                         8

X Coefficient(s)     0.011427
Std Err of Coef.     0.000451
```

## TABLE 9.2

```
====================================
PROPELLER AND NOZZLE BOLLARD PULL/RPS
REGRESSION DATA
====================================

         Regression Output:
Constant                          -87.14
Std Err of Y Est                    8.00
R Squared                           0.98
No. of Observations                 6.00
Degrees of Freedom                  4.00

X Coefficient(s)      39.71
Std Err of Coef.       2.55
```

Figure 9.2



TOTAL THRUST AS FUNCTION OF RPS

BOLLARD CONDITION

Figure 9.3a

```
RUN NO.   2     TOTAL NO. OF SAMPLES =  1060      26-APR-1988 16:20:38
T1 =    0.2200 SEC.      T2 =    3.7400 SEC.

P     # R4034 BOLLARD/SELF PROPULSION
B   ARD TEST, 100 % POWER

CH DESCRIPTION                           AVERAGE        RMS       MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)                  0.00076      0.00239    -0.01188      0.01753
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -1.51247      0.68423    -4.58301     -0.03512
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.86458      0.67365    -2.31977      0.77561
 4 CENTRE THRUST (N)                     3.98671     60.48479   -78.49004    103.33528
 5 CENTRE TORQUE (Nm)                    2.74688      0.75708     1.15349      4.33010
 6 TOW FORCE (N)                      -450.60582      5.89247  -461.27390   -439.54239
 7 PORT SHAFT SPEED (RPS)                8.49991      0.00298     8.49050      8.51112
 8 CENTRE SHAFT SPEED (RPS)              6.54759      0.01208     6.51114      6.59586
 9 STRBRD. SHAFT SPEED (RPS)             8.52420      0.00994     8.50787      8.54438
10 NOZZLE BN [#1 GAUGE] (Nm)            18.94630      1.01595    16.47083     21.39396
11 NOZZLE BN [#2 GAUGE] (Nm)            20.79699      1.07826    18.06970     23.22303
12 NOZZLE BN [#3 GAUGE] (Nm)            22.60678      1.13720    19.78255     25.14386
13 NOZZLE TORSION [ #1 Gg] (Nm)          0.17033      0.66475    -1.17670      2.80075

--------------------------------------------------------------------------------

RUN NO.   2     TOTAL NO. OF SAMPLES =  1060      26-APR-1988 16:20:38
T1 =    3.9800 SEC.      T2 =    7.8400 SEC.

  OJ. # R4034 BOLLARD/SELF PROPULSION
    ARD TEST, 100 % POWER

CH DESCRIPTION                           AVERAGE        RMS       MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)                  0.00059      0.00096    -0.00331      0.00372
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -1.34457      0.71538    -3.10170      0.51062
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.72366      0.73232    -2.48268      1.18289
 4 CENTRE THRUST (N)                     4.74686     60.72631   -79.32536    104.60845
 5 CENTRE TORQUE (Nm)                    2.62423      0.76408     1.14311      4.12940
 6 TOW FORCE (N)                      -446.73172      2.61681  -453.66788   -442.15018
 7 PORT SHAFT SPEED (RPS)                8.50060      0.00494     8.48983      8.53339
 8 CENTRE SHAFT SPEED (RPS)              6.54794      0.01143     6.49250      6.57553
 9 STRBRD. SHAFT SPEED (RPS)             8.52400      0.01021     8.49541      8.55863
10 NOZZLE BN [#1 GAUGE] (Nm)            18.96362      0.90129    16.61250     21.64189
11 NOZZLE BN [#2 GAUGE] (Nm)            20.88701      0.98162    18.31510     23.99428
12 NOZZLE BN [#3 GAUGE] (Nm)            22.66366      1.01739    19.96126     25.82296
13 NOZZLE TORSION [ #1 Gg] (Nm)          0.30535      0.70778    -1.39921      2.30009

--------------------------------------------------------------------------------

RUN NO.   2     TOTAL NO. OF SAMPLES =  1060      26-APR-1988 16:20:38
T1 =    8.9000 SEC.      T2 =   12.3000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD TEST. 100 % POWER

     SCRIPTION                           AVERAGE        RMS       MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)                  0.00091      0.00220    -0.00475      0.01483
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -1.67631      0.77798    -3.38756     -0.11309
```

Figure 9.3b

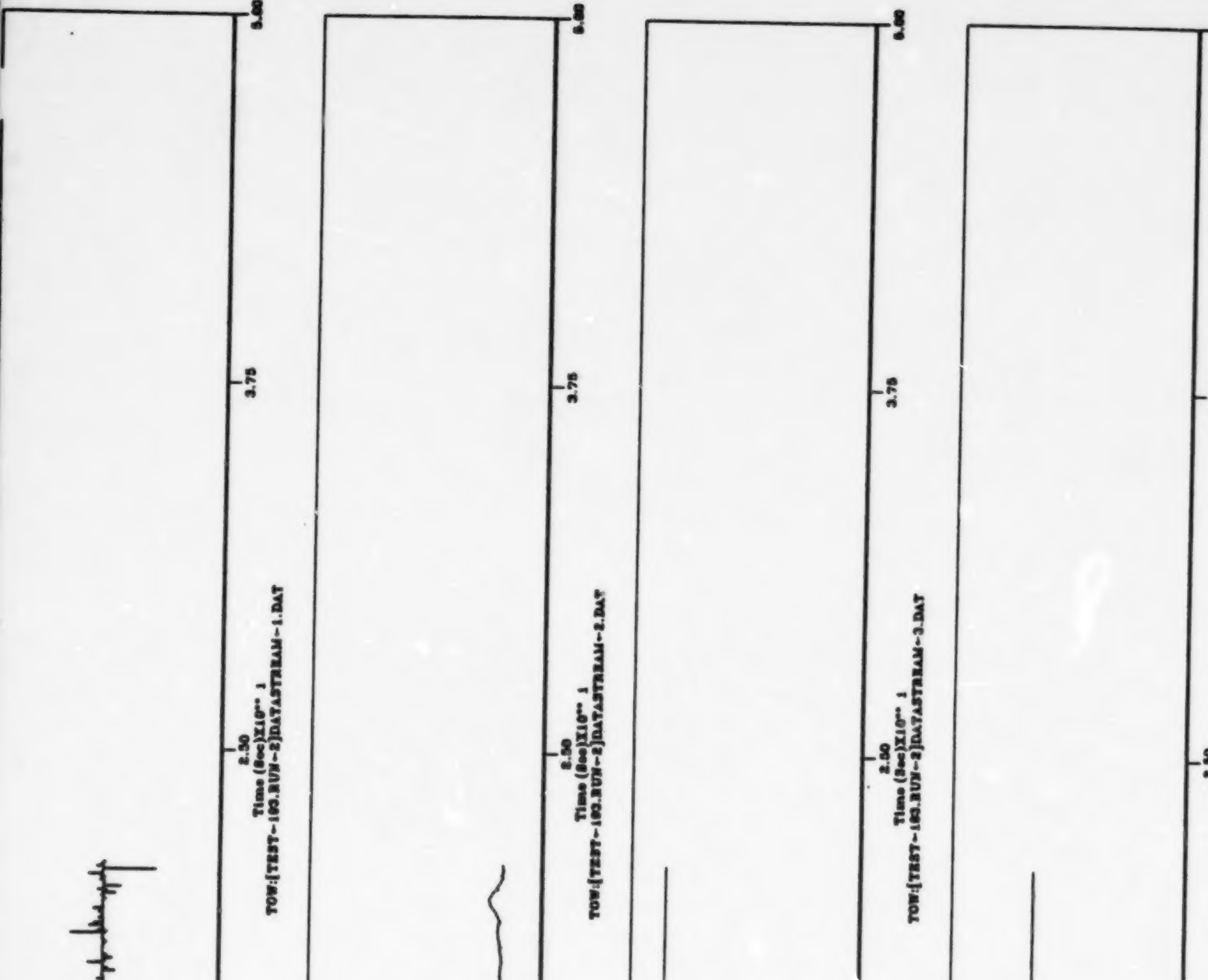
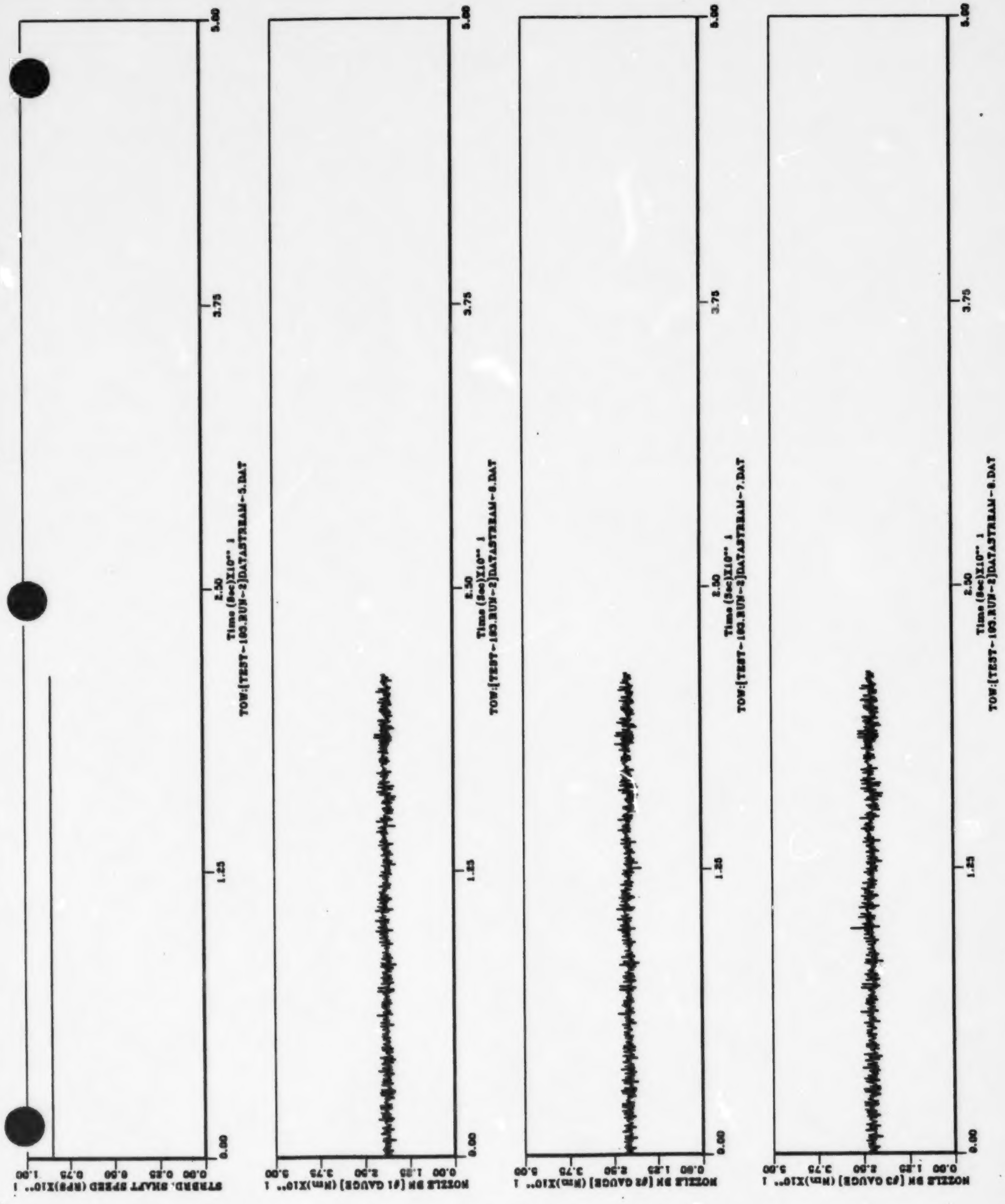

CARRIAGE SPEED (M/S)X10**
-5.00 -2.50 0.00 2.50
TOW FORCE (N)X10** 2
-5.00 -4.25 -3.50 -2.75 -2.00
PORT SHAFT SPEED (RPS)X10** 1
0.00 0.25 0.50 0.75 1.00
CENTRE SHAFT SPEED (RPS)X10** 1
0.00 0.25 0.50 0.75 1.00
0.00 1.25 2.50 3.75 5.00
Time (Sec)X10** 1
TOW:[TEST-183.RUN-2]DATASTREAM-1.DAT
TOW:[TEST-183.RUN-2]DATASTREAM-2.DAT
TOW:[TEST-183.RUN-2]DATASTREAM-3.DAT
TOW:[TEST-183.RUN-2]DATASTREAM-4.DAT

Figure 9.3c



STBRD. SHAFT SPEED (RPS)X10** 1
0.00 0.25 0.50 0.75 1.00
0.00 1.25 2.50 3.75 5.00
Time (Sec)X10** 1
TOW:[TEST-103.RUN-2]DATASTREAM-5.DAT
NOZZLE DN [#1 GAUGE] (Nm)X10** 1
0.00 1.25 2.50 3.75 5.00
0.00 1.25 2.50 3.75 5.00
Time (Sec)X10** 1
TOW:[TEST-103.RUN-2]DATASTREAM-6.DAT
NOZZLE DN [#2 GAUGE] (Nm)X10** 1
0.00 1.25 2.50 3.75 5.00
0.00 1.25 2.50 3.75 5.00
Time (Sec)X10** 1
TOW:[TEST-103.RUN-2]DATASTREAM-7.DAT
NOZZLE DN [#3 GAUGE] (Nm)X10** 1
0.00 1.25 2.50 3.75 5.00
0.00 1.25 2.50 3.75 5.00
Time (Sec)X10** 1
TOW:[TEST-103.RUN-2]DATASTREAM-8.DAT

TABLE ... 9.4

SUMMARY OF OVERLOAD TESTS

| % RPS<br>(8=100%) | THRUST IN % OF 232.5<br>NOZZLE | <br>PROP | <br>TOTAL | TORQUE IN %<br>OF 7.84 | TOW PULL<br>% OF 232. | LOCATION OF NOZZLE THRUST<br>Z/DIA | <br>Y/DIA |
|---|---|---|---|---|---|---|---|
| | BOLLARD AHEAD | | | | | | |
| 88.84 | 50.75 | 36.03 | 86.78 | 69.90 | 198.28 | 6.20% | -2.54% |
| 88.71 | 49.46 | 36.17 | 85.63 | 68.28 | 206.71 | -10.06% | -4.75% |
| 79.59 | 40.00 | 30.54 | 70.54 | 53.01 | 192.04 | -9.15% | -3.22% |
| 72.14 | 35.05 | 26.02 | 61.07 | 45.10 | 142.92 | -3.13% | -4.42% |
| 60.10 | 23.01 | 19.60 | 42.60 | 33.05 | 82.41 | -3.34% | -4.06% |
| 44.07 | 11.48 | 13.62 | 25.10 | 19.73 | 46.37 | -22.29% | -5.77% |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00% | 0.00% |
| | 5 KNOTS AHEAD | | | | | | |
| 41.39 | 4.14 | 9.65 | 13.79 | 15.50 | 13.65 | 7.77% | 8.12% |
| 60.34 | 11.26 | 16.49 | 27.74 | 29.04 | 42.71 | -13.11% | 0.28% |
| 71.13 | 18.74 | 21.88 | 40.62 | 41.25 | 83.66 | -9.52% | -0.79% |
| 87.24 | 32.87 | 31.98 | 64.85 | 57.72 | 150.32 | -4.10% | -1.43% |
| | 10 KNOTS AHEAD | | | | | | |
| 42.64 | -1.29 | 7.90 | 6.61 | 11.48 | -13.90 | -32.87% | -42.20% |
| 59.56 | 7.75 | 9.49 | 17.24 | 21.68 | -13.29 | 84.96% | 0.53% |
| 69.29 | 10.44 | 14.98 | 25.42 | 27.17 | 19.04 | 26.25% | -0.50% |
| 87.25 | 20.81 | 26.02 | 46.82 | 48.69 | 77.42 | 7.83% | -2.32% |
| | 15 KNOTS AHEAD | | | | | | |
| 44.66 | -7.58 | 10.18 | 2.60 | -17.03 | -110.62 | -8.75% | -12.78% |
| 44.70 | -10.25 | 11.05 | 0.80 | -15.31 | -136.77 | 29.12% | -11.05% |
| 64.33 | -0.89 | 9.49 | 8.60 | 19.13 | -98.37 | -199.54% | -15.77% |
| 79.81 | 5.24 | 9.97 | 15.20 | 38.27 | -25.46 | -9.53% | -3.98% |
| | BOLLARD ASTERN | | | | | | |
| -90.04 | -37.86 | -47.74 | -85.60 | -81.62 | -127.35 | 0.42% | -0.80% |
| -89.88 | -41.09 | -50.00 | -91.09 | -77.19 | -56.77 | 8.49% | 0.20% |
| -73.10 | -24.74 | -32.00 | -56.74 | -51.02 | -83.40 | 0.16% | 1.84% |
| -60.79 | -13.11 | -17.91 | -31.02 | -44.01 | -50.02 | -58.12% | 1.69% |
| -44.64 | -7.30 | -10.74 | -18.05 | -24.67 | -26.74 | -34.33% | 3.50% |
| | 2 KNOTS ASTERN | | | | | | |
| -43.90 | -9.71 | -9.20 | -18.91 | -21.36 | -18.30 | 77.63% | 0.93% |
| -66.96 | -21.28 | -20.13 | -41.41 | -42.51 | -46.67 | 45.53% | 0.11% |
| -77.70 | -27.61 | -26.57 | -54.18 | -54.39 | -79.01 | 35.03% | 1.00% |
| -88.59 | -34.10 | -36.36 | -70.46 | -68.99 | -111.01 | 21.90% | 0.74% |
| | 4 KNOTS ASTERN | | | | | | |
| -43.75 | -4.11 | -10.42 | -14.53 | -19.39 | -5.09 | 101.33% | 0.86% |
| -59.45 | -9.09 | -17.14 | -26.23 | -31.90 | -25.76 | 46.16% | 1.40% |
| -75.54 | -18.08 | -26.18 | -44.26 | -48.62 | -59.05 | 36.65% | 3.70% |
| -87.90 | -25.65 | -34.59 | -60.24 | -63.90 | -88.47 | 30.74% | 1.18% |
| | 6 KNOTS ASTERN | | | | | | |
| -44.05 | -3.52 | -3.08 | -6.61 | -16.38 | 11.74 | 215.19% | 2.71% |
| -67.34 | -11.84 | -13.94 | -25.77 | -36.21 | -9.27 | 106.48% | -2.24% |
| -82.33 | -20.34 | -23.69 | -44.03 | -54.62 | -40.27 | 76.70% | 1.24% |
| -106.44 | -37.33 | -43.70 | -81.03 | -89.82 | -86.58 | 49.81% | 0.67% |

Figure 9.4

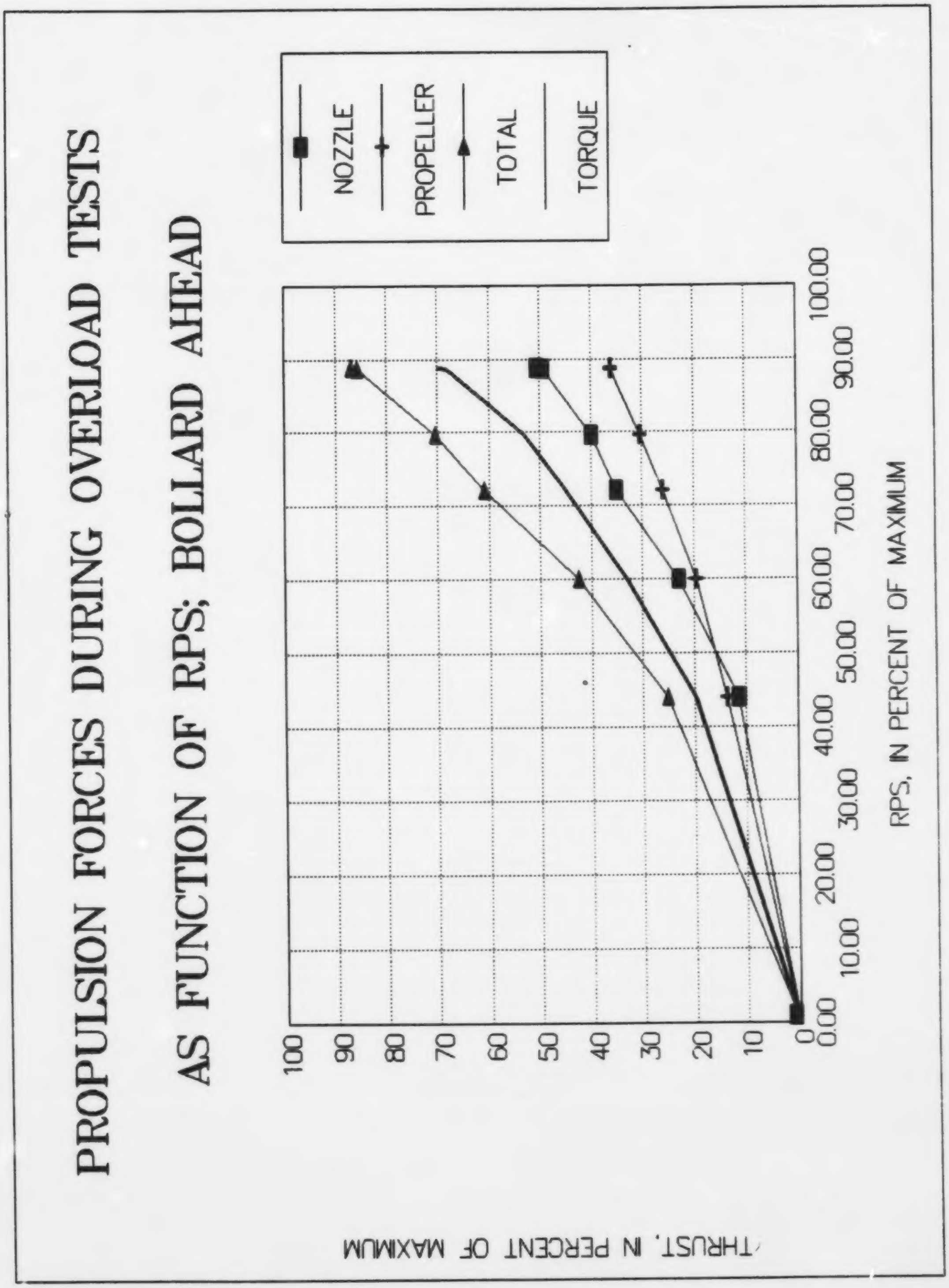
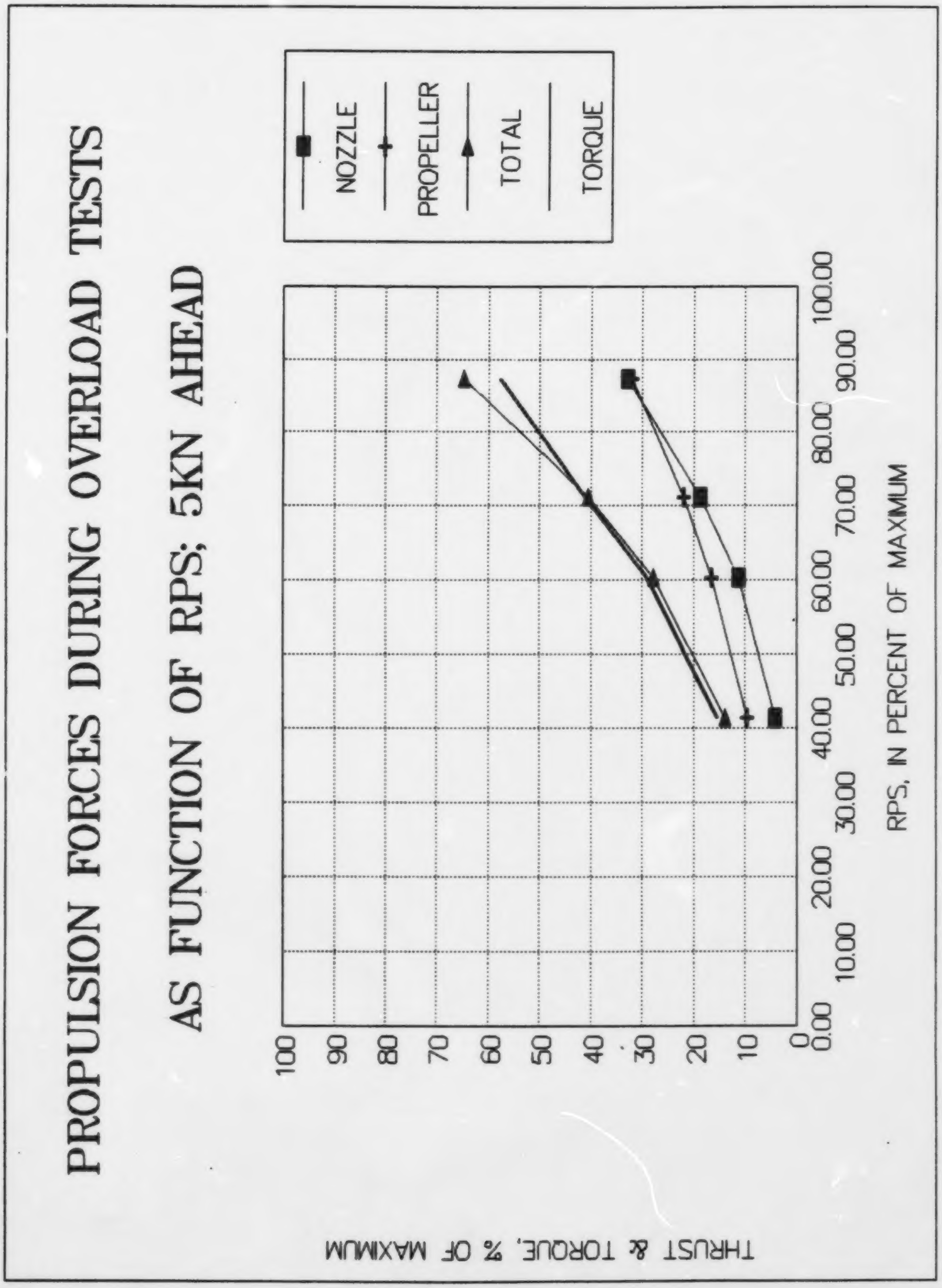

PROPULSION FORCES DURING OVERLOAD TESTS AS FUNCTION OF RPS; BOLLARD AHEAD

Figure 9.5


PROPULSION FORCES DURING OVERLOAD TESTS
AS FUNCTION OF RPS; 5KN AHEAD
NOZZLE
PROPELLER
TOTAL
TORQUE
THRUST & TORQUE, % OF MAXIMUM
100
90
80
70
60
50
40
30
20
10
0
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
RPS, IN PERCENT OF MAXMUM

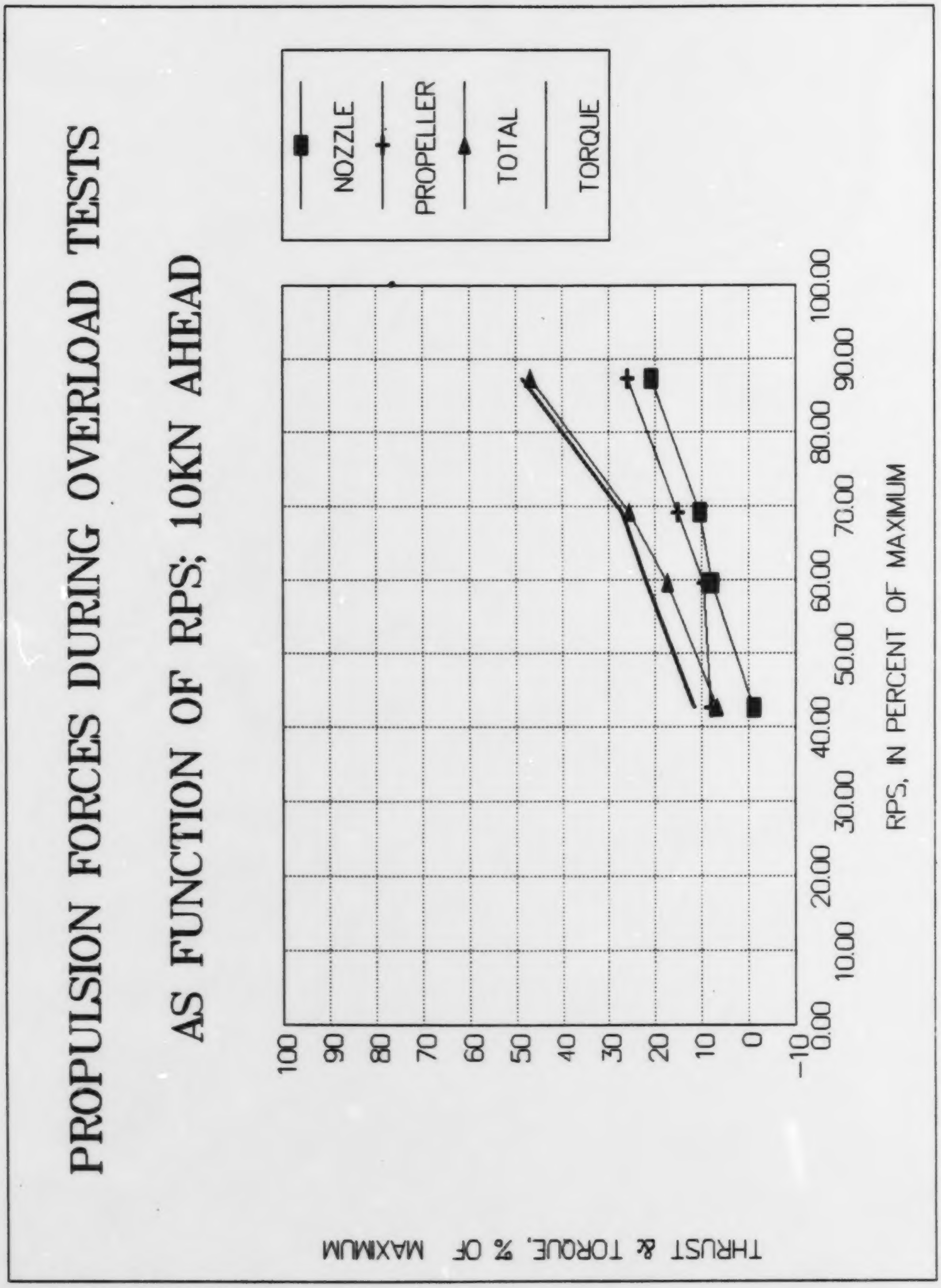

PROPULSION FORCES DURING OVERLOAD TESTS
AS FUNCTION OF RPS; 10KN AHEAD
NOZZLE
PROPELLER
TOTAL
TORQUE
THRUST & TORQUE, % OF MAXIMUM
100
90
80
70
60
50
40
30
20
10
0
-10
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
RPS, IN PERCENT OF MAXIMUM

Figure 9.7

## PROPULSION FORCES DURING OVERLOAD TESTS

## AS FUNCTION OF RPS; 15KN AHEAD

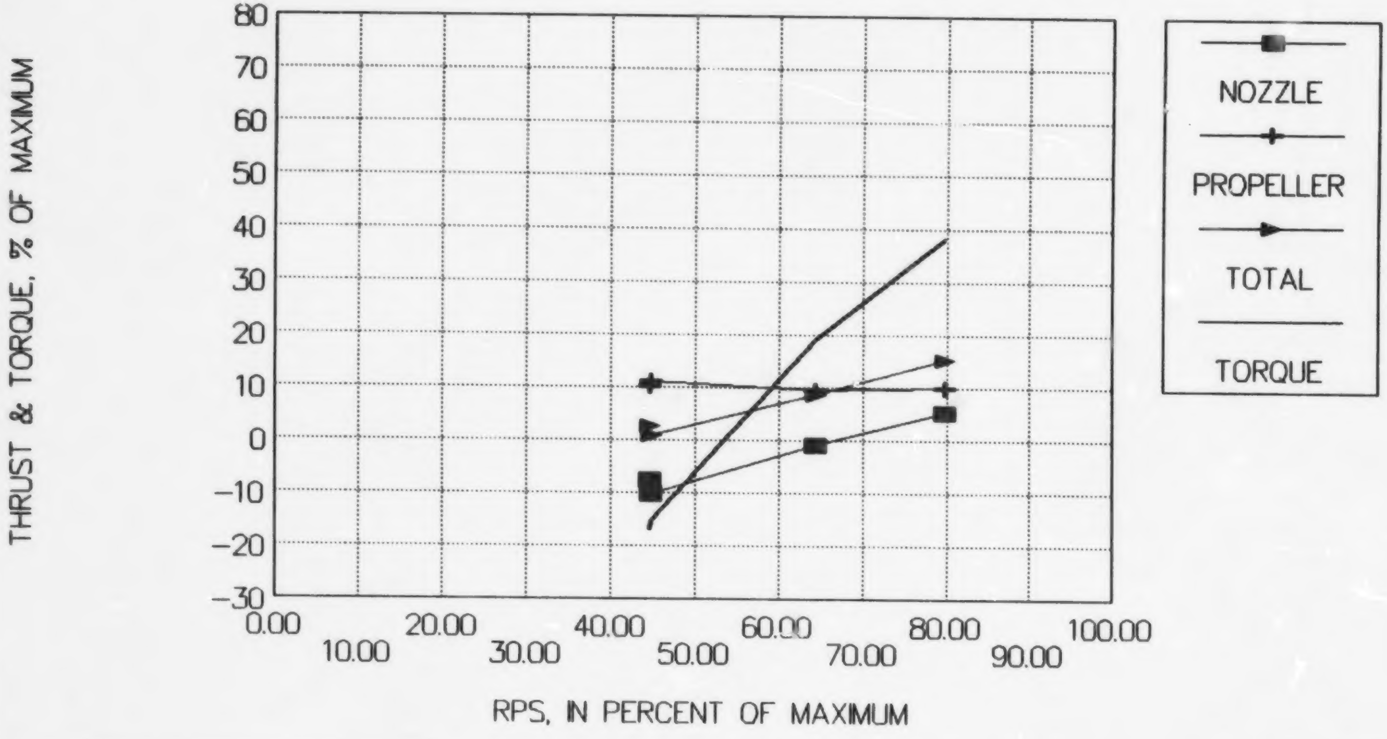
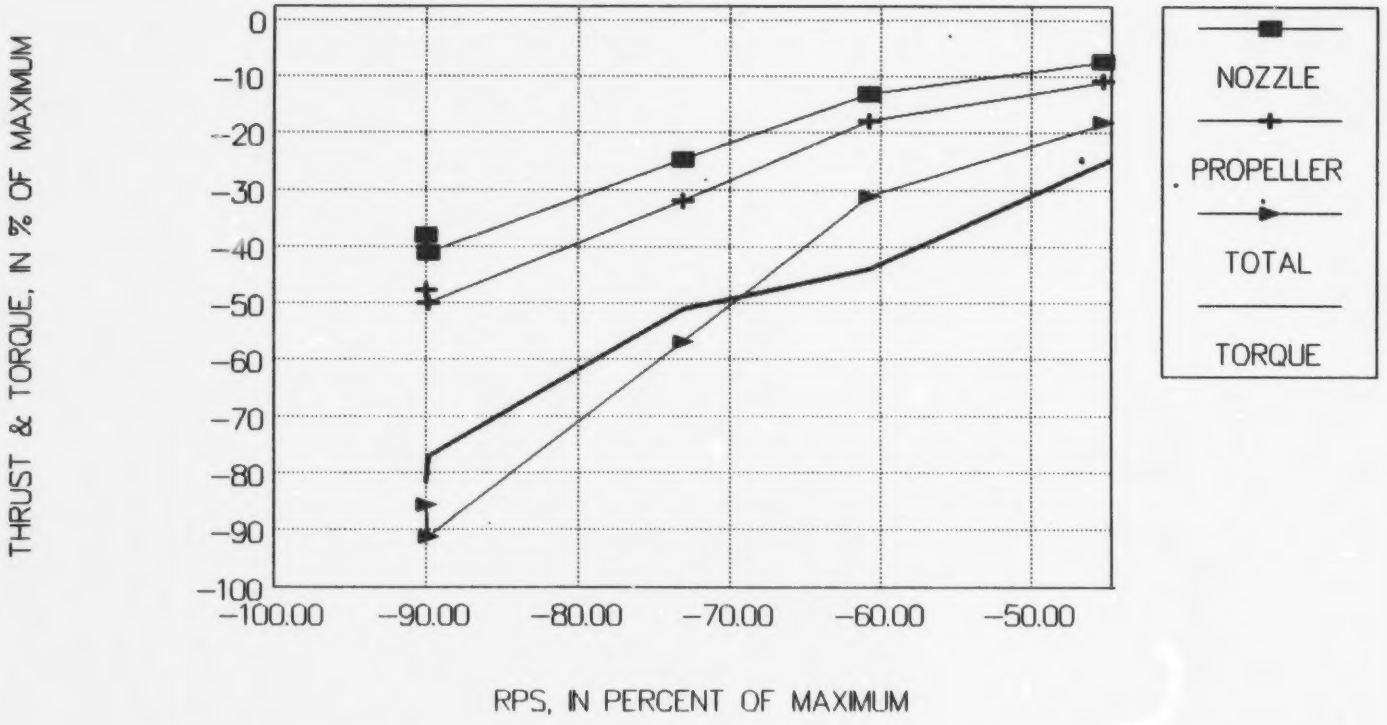


Figure 9.8



PROPULSION FORCES DURING OVERLOAD TE
AS FUNCTION OF RPS; BOLLARD ASTERN

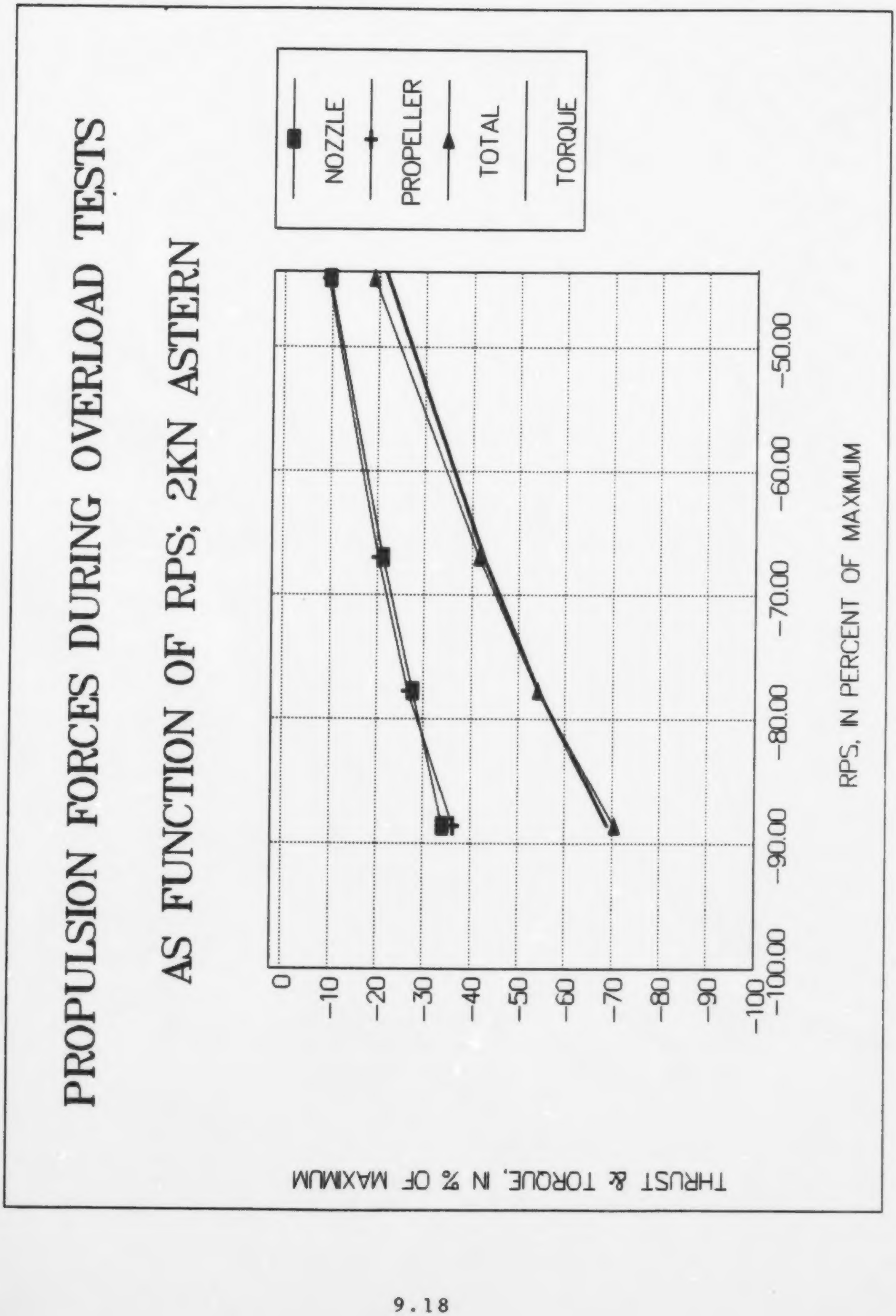

PROPULSION FORCES DURING OVERLOAD TESTS
AS FUNCTION OF RPS; 2KN ASTERN
NOZZLE
PROPELLER
TOTAL
TORQUE
THRUST & TORQUE, IN % OF MAXIMUM
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-100.00
-90.00
-80.00
-70.00
-60.00
-50.00
RPS, IN PERCENT OF MAXIMUM

Figure 9.10

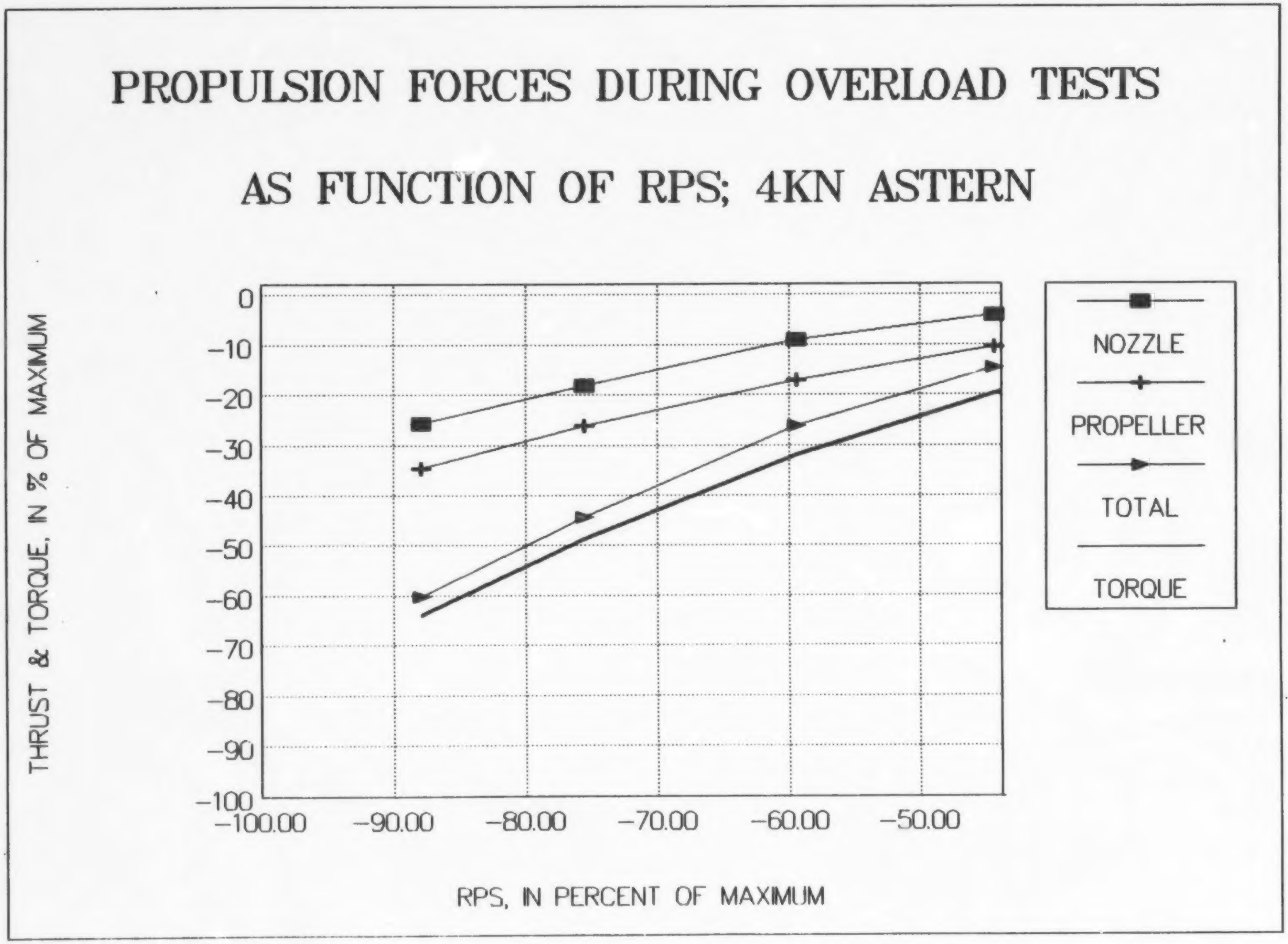

PROPULSION FORCES DURING OVERLOAD TESTS AS FUNCTION OF RPS; 4KN ASTERN

Figure 9.11

## PROPULSION FORCES DURING OVERLOAD TESTS AS FUNCTION OF RPS; 6KN ASTERN

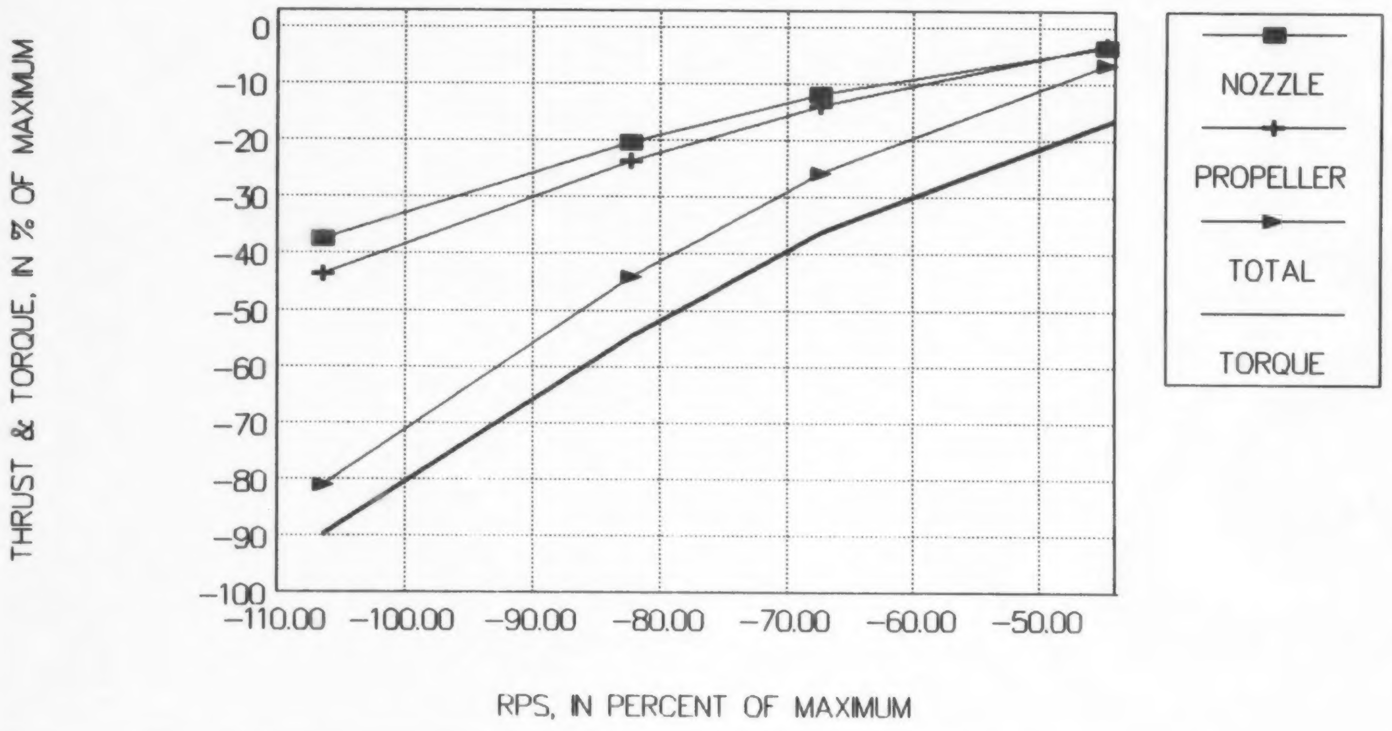
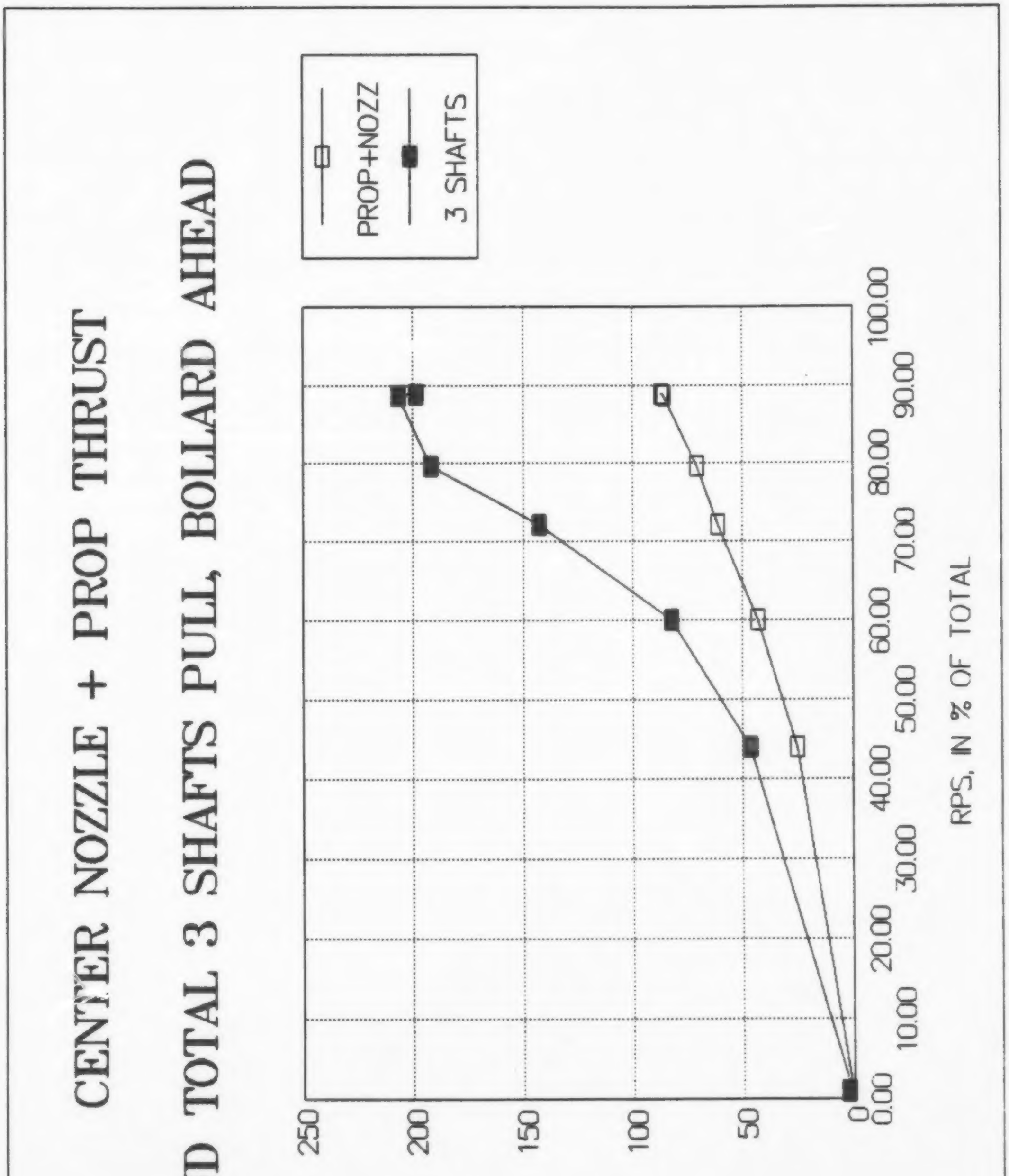


Figure 9.12



CENTER NOZZLE + PROP THRUST

AND TOTAL 3 SHAFTS PULL, BOLLARD AHEAD

Figure 9.13

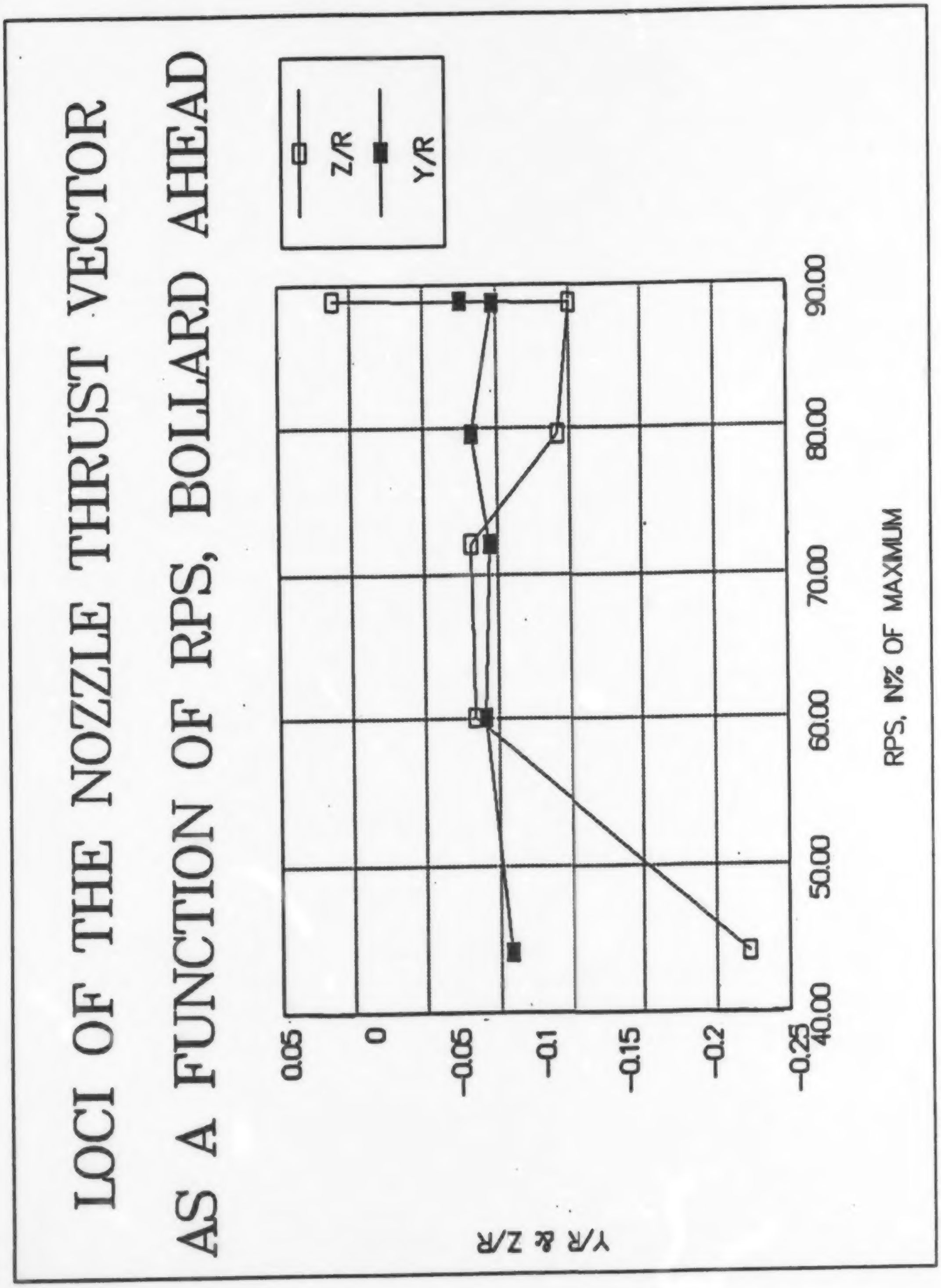
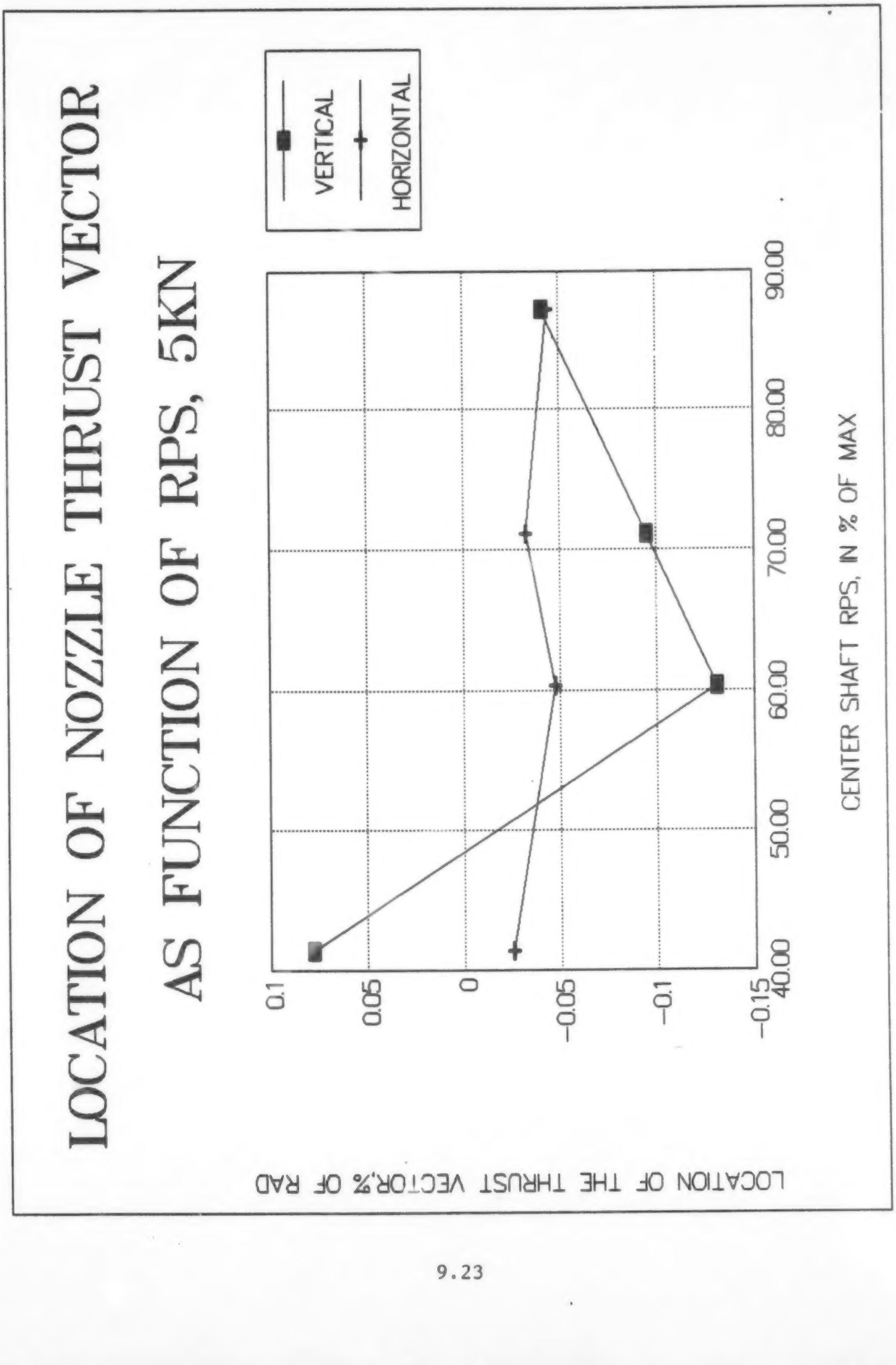
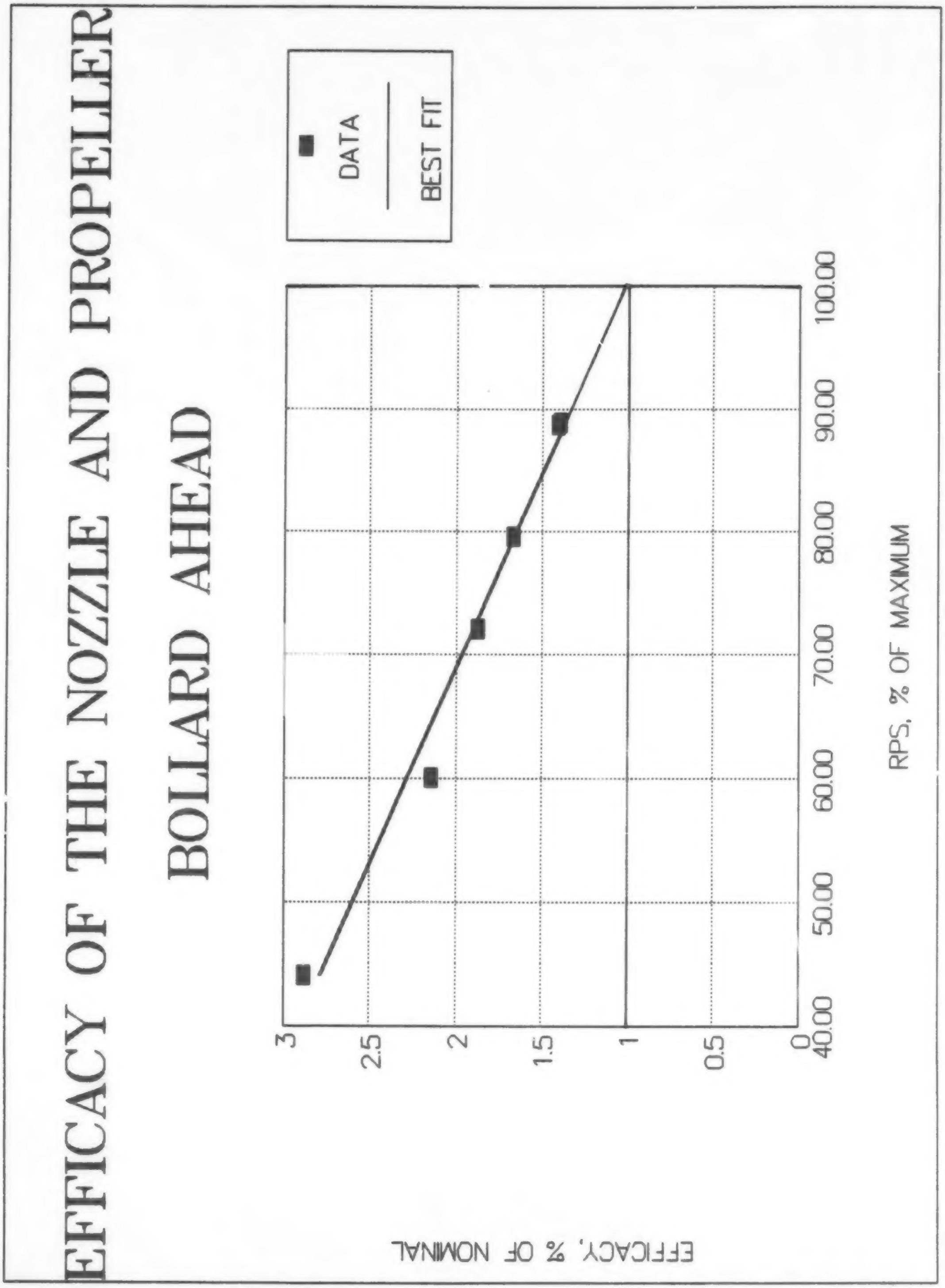

LOCI OF THE NOZZLE THRUST VECTOR
AS A FUNCTION OF RPS, BOLLARD AHEAD
Z/R
Y/R
Y/R & Z/R
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
40.00
50.00
60.00
70.00
80.00
90.00
RPS, N% OF MAXIMUM

Figure 9.14



LOCATION OF NOZZLE THRUST VECTOR AS FUNCTION OF RPS, 5KN

Figure 9.15



EFFICACY OF THE NOZZLE AND PROPELLER BOLLARD AHEAD

TABLE 9.5

NONDIMENSIONAL EFFICACY COEFFICIENTS /CENTER ONLY

| RPS IN % OF 8 | NOZZLE THRUST | PROPELLER THRUST | TORQUE IN % OF 7.84NM | POWER IN % OF 394 W | TOW ROPE PULL IN % OF 232.5N | TOW PULL/ POWER | THRUST |
|---|---|---|---|---|---|---|---|
| | IN % OF 232.5N | | | | | IN % OF NOMINAL | |
| BOLLARD AHEAD | | | | | | | |
| 88.84 | 50.75 | 36.03 | 68.50 | 60.85 | 69.42 | 114.08 | 79.99 |
| 100.00 | 53.51 | 49.63 | 94.10 | 94.10 | 84.82 | 90.14 | 82.24 |
| 93.75 | 45.98 | 43.31 | 82.25 | 77.11 | 73.51 | 95.33 | 82.32 |
| 100.44 | 55.83 | 49.42 | 98.88 | 99.31 | 77.63 | 78.18 | 73.76 |
| 99.75 | 51.83 | 49.38 | 92.25 | 92.02 | 77.42 | 84.13 | 76.50 |
| 87.38 | 49.03 | 41.40 | 67.63 | 59.09 | 61.46 | 104.02 | 67.96 |
| BOLLARD ASTERN | | | | | | | |
| -100.75 | -44.60 | -56.65 | -117.38 | -118.26 | -64.00 | 54.12 | 63.21 |
| -105.44 | -45.70 | -62.71 | -125.00 | -131.80 | -71.53 | 54.27 | 65.98 |
| -105.13 | -47.87 | -62.41 | -117.63 | -123.65 | -70.41 | 56.94 | 63.85 |
| -107.75 | -60.86 | -42.05 | -105.62 | -113.81 | -80.60 | 70.82 | 78.32 |

TABLE 9.6
THRUST DEDUCTION FACTOR

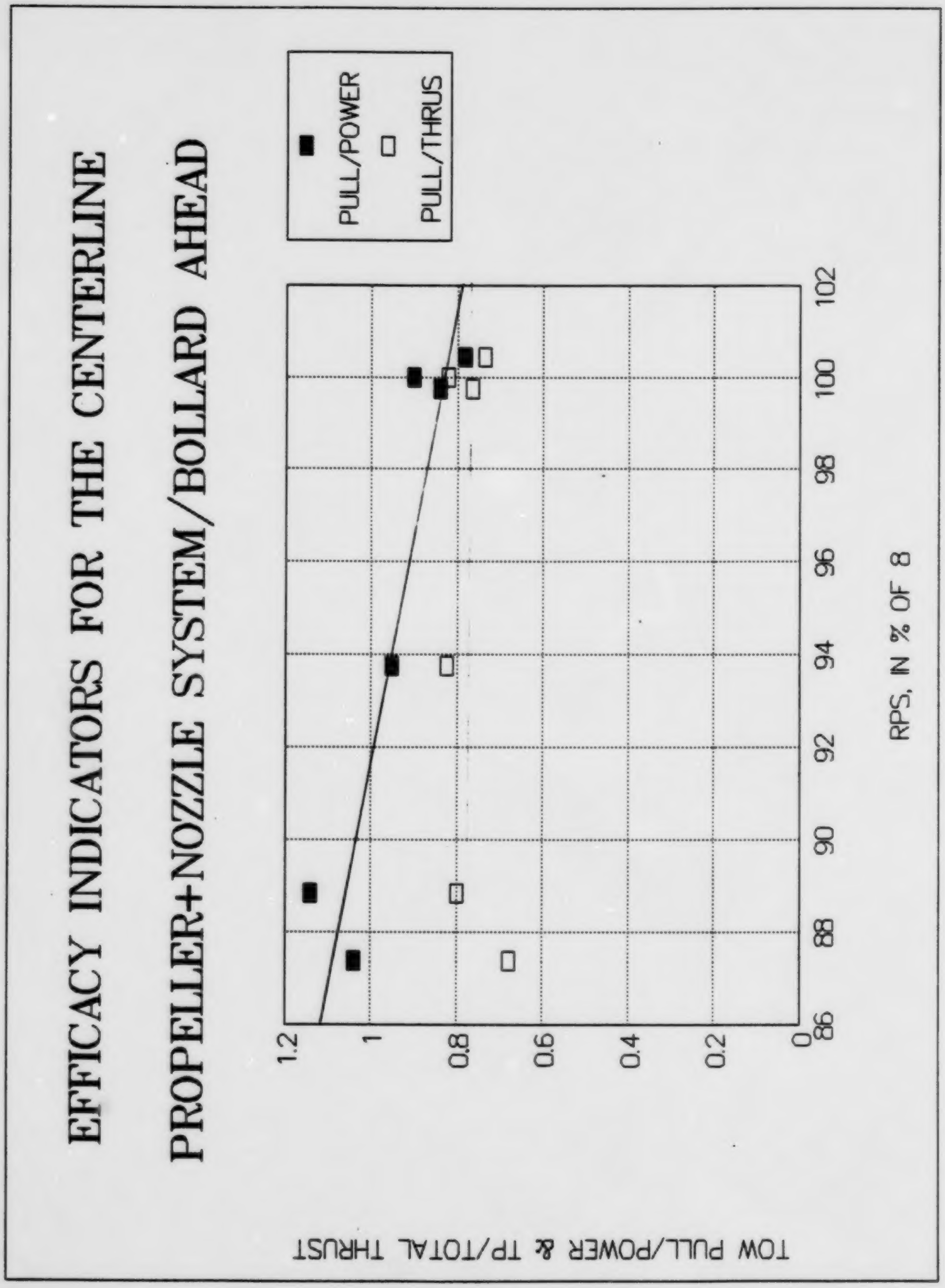
BOLLARD AHEAD

| RPS | NOZZLE THRUST | PROPELLER THRUST | TORQUE | POWER | TOW ROPE PULL | THRUST DEDUCTION |
|---|---|---|---|---|---|---|
| 7.11 | 118 | 83.77 | 5.48 | 0.62 | 161.4 | 0.20 |
| 8.00 | 124.4 | 115.4 | 7.528 | 0.96 | 197.2 | 0.18 |
| 7.50 | 106.9 | 100.7 | 6.58 | 0.79 | 170.9 | 0.18 |
| 8.04 | 129.8 | 114.9 | 7.91 | 1.01 | 180.5 | 0.26 |
| 7.98 | 120.5 | 114.8 | 7.38 | 0.94 | 180 | 0.24 |
| 6.99 | 114 | 96.26 | 5.41 | 0.60 | 142.9 | 0.32 |
| | | | AVERAGE | 0.82 | | 0.23 |

BOLLARD ASTERN

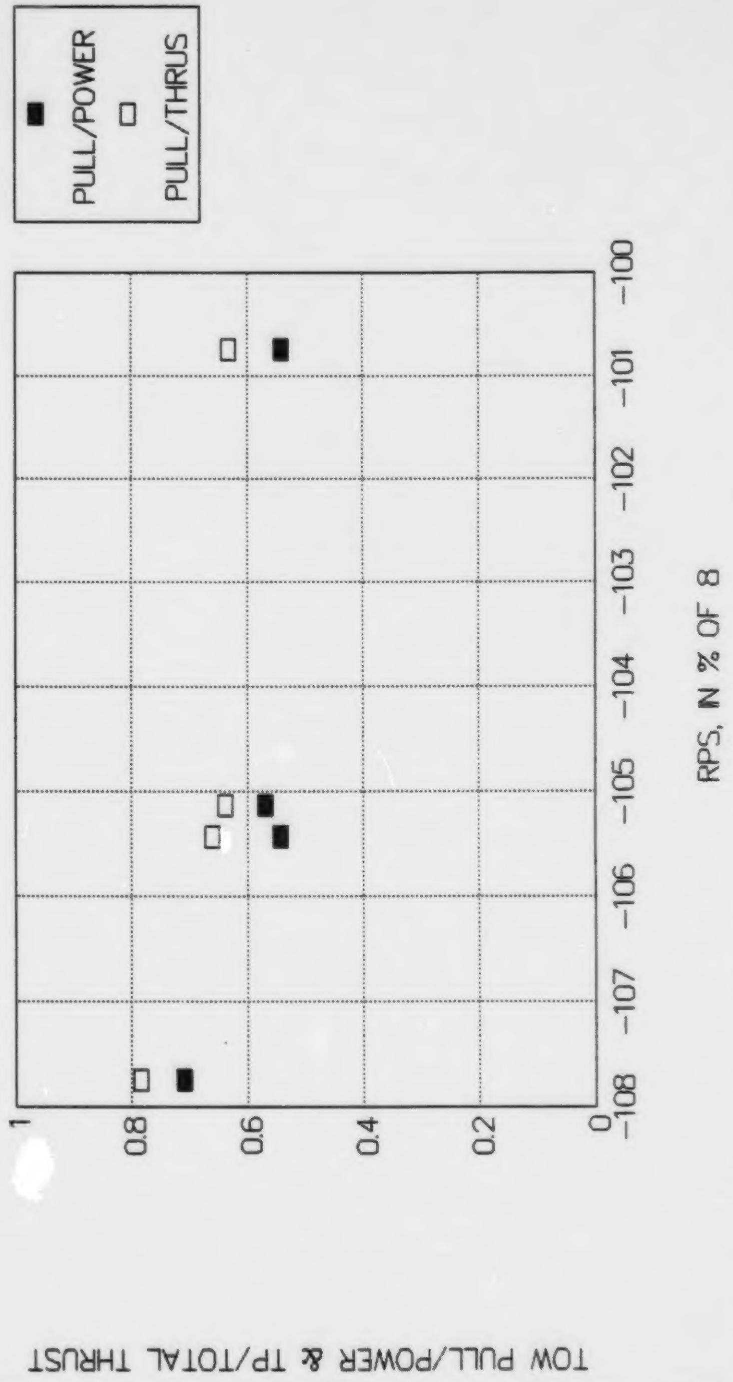
| RPS | NOZZLE THRUST | PROPELLER THRUST | TORQUE | POWER | TOW ROPE PULL | THRUST DEDUCTION |
|---|---|---|---|---|---|---|
| -8.06 | -103.7 | -131.7 | -9.39 | -1.21 | -148.8 | 0.37 |
| -8.44 | -106.25 | -145.8 | -10 | -1.34 | -166.3 | 0.34 |
| -8.41 | -111.3 | -145.1 | -9.41 | -1.26 | -163.7 | 0.36 |
| -8.62 | -141.5 | -97.77 | -8.45 | -1.16 | -187.4 | 0.22 |
| | | | AVERAGE | -1.24 | | 0.32 |

Figure 9.16



EFFICACY INDICATORS FOR THE CENTERLINE PROPELLER+NOZZLE SYSTEM/BOLLARD AHEAD

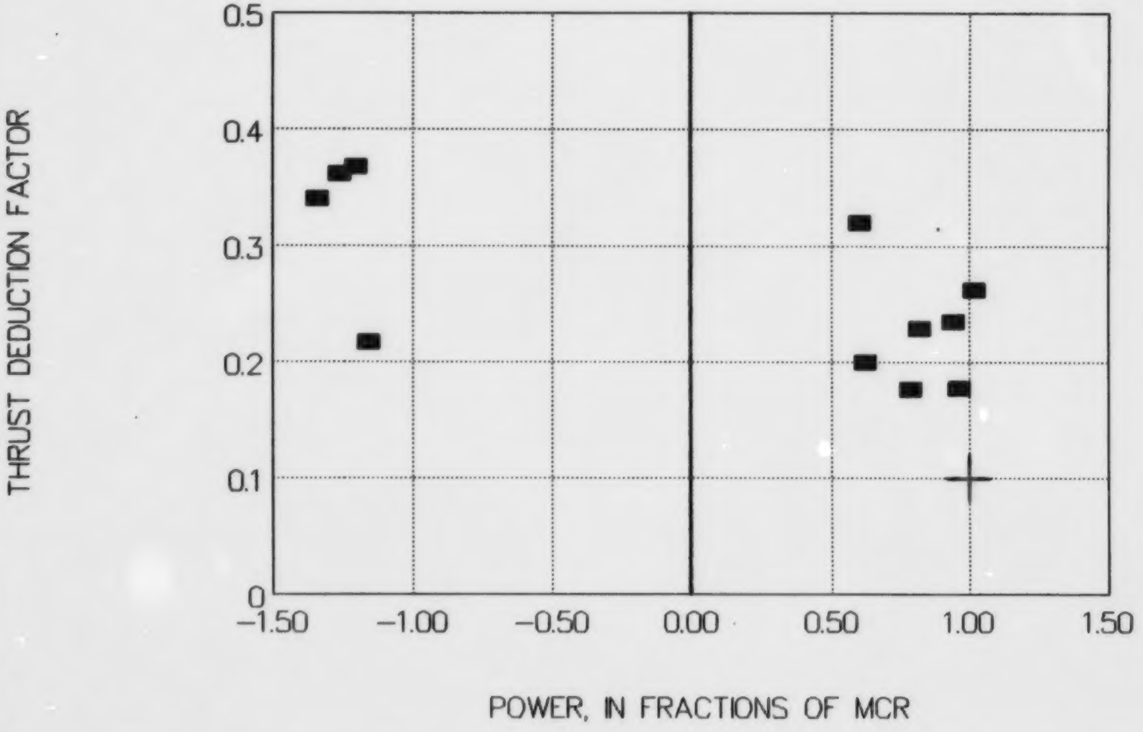
Figure 9.17



EFFICACY INDICATORS FOR THE CENTERLINE PROPELLER+NOZZLE SYSTEM/BOLLARD ASTERN

Figure 9.18

## THRUST DEDUCTION FACTOR FOR THE CENTER PROPELLER AND NOZZLE, WINGS STOPPED



## *10. THRUST CHANGE OF THE CENTER PROPELLER/NOZZLE SYSTEM AS A RESULT OF WING PROPELLERS INTERFERENCE.*

### *10.1* ***Tests findings***

*During the propulsion tests of the model of the triple screw icebreaker CCGS Louis S. St Laurent (scale 1:15) we observed a change of the nozzle support loads due to the change of power level of the model.*

*This change was recorded in Figure 10.1, where bending moments (raw data) is plotted for all three nozzle support bending gauges, for varying wing propeller power levels, and bollard condition.*

*The zero corrected bending moments are shown in Figure 10.2, for the three gauges and varying power levels.*

*Figure 10.3 shows the same information, but as a direct function of the wing power level. The pronounced increase of the support bending is very evident.*

*The reason for the change is evident:*

> *the wing propellers water flow field (slipstream) interferes with the center propeller intake, for bollard ahead condition.*
>
> *for the astern condition, even stronger interference is observed.*

*The center and wing propellers of the model are configured as follows:*

*TABLE 10.1*

*WING AND CENTER PROPELLER CONFIGURATION*

| | rake up deg | rake out deg | offset vert m | offset horiz m | long spacing m | hydrodyn diameter m | disk clear'ce m |
|---|---|---|---|---|---|---|---|
| center | 1.9 | 0.0 | 0.205 | 0.00 | 0.00 | 0.346 | 0.000 |
| wing | 1.6 | 3.7 | 0.207 | 0.33 | 0.29 | 0.305 | 0.004 |

*Disk clearance is practically nil, that is the wing propeller disk "touches" the centerline nozzle disk area.*

*The slipstream divergence 1/2 angles were computed and shown in Figure 10.4. It is clear that for the near bollard condition and 50N to 100N propeller thrust, the half angle of slipstream divergence is 12.5 degrees. This divergence translates into the transverse "overlap" of 0.06m of the hydrodynamic disk areas. This was sufficient to create the disturbance.*
*This interference is visible also when examining the locus of the nozzle thrust as shown in Figure 10.5.*

*The ratio of the thrust/power delivered to the centerline propeller/nozzle system as a function of the wing power level is shown in the Figure 10.6. Due to the present uncertainty in the gauge readings two curves are shown:*

*average, and*
*maximum*

*for the bollard ahead and, in Figure 10.7, for the bollard astern.*

*Table 10.2 gives the details of the gauge readings and results of the powering computations.*

## 10.2 Conclusions of this investigation:

*There is sufficient data to conclude that the wing propellers* **cause considerable disturbance** *in the working of the centerline propeller and nozzle.*

*For the full power ahead, a* **considerable gain** *in the nozzle can be anticipated, by an analogy with the axial pumps working in series. For the astern condition,* **severe penalty** *in the centerline thrust may take place.*

*This issue is an important one in deciding on the geometry of the triple screw propulsion layout and the power distribution between the shafts. A testing programme specifically designed to investigate this problem should be implemented.*

Figure 10.1

CHANGE OF NOZZLE SUPPORT BENDING

AS FUNCTION OF WING PROPS POWER LEVEL

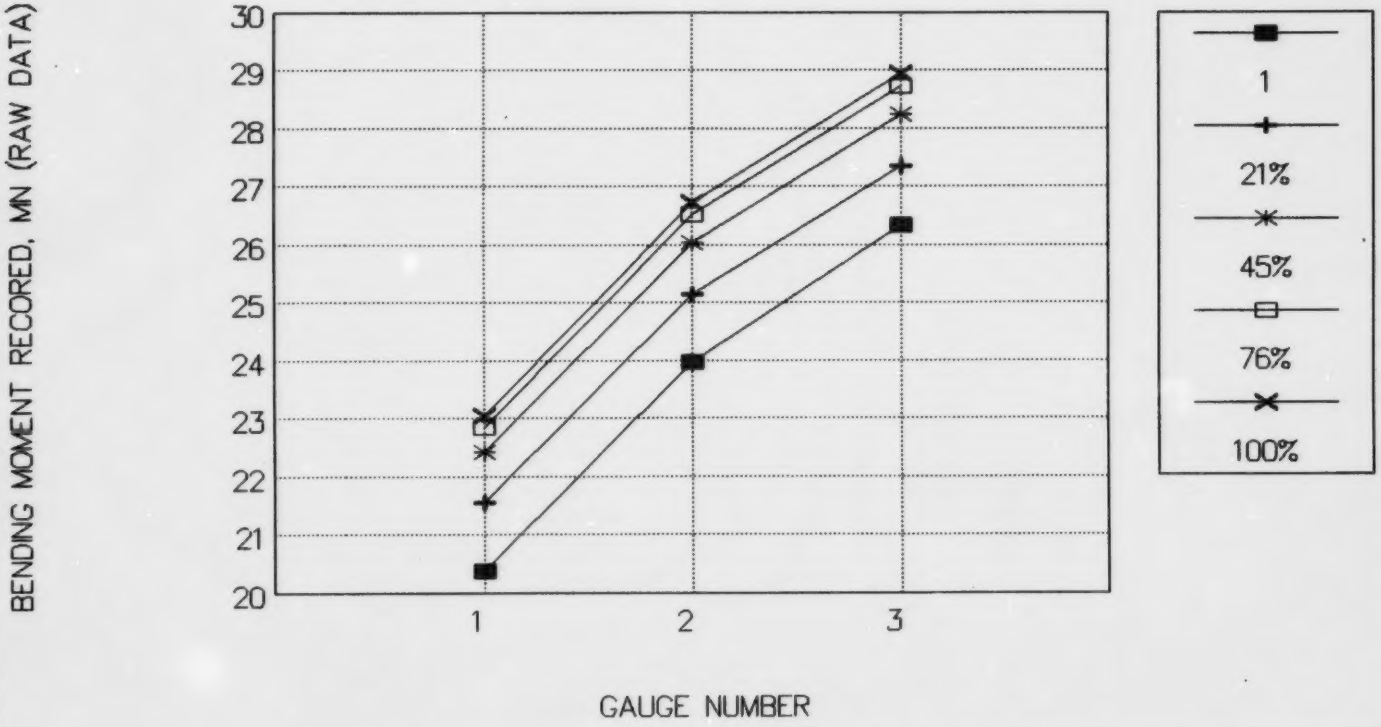
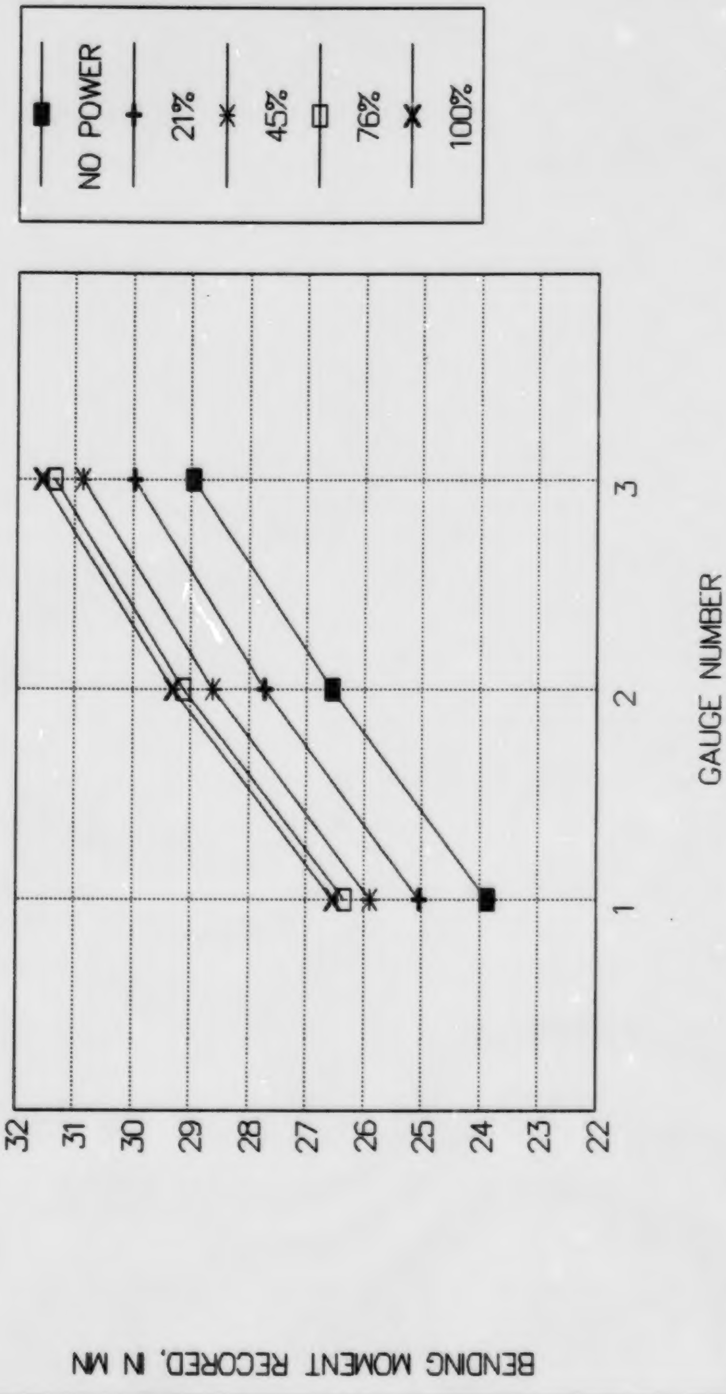
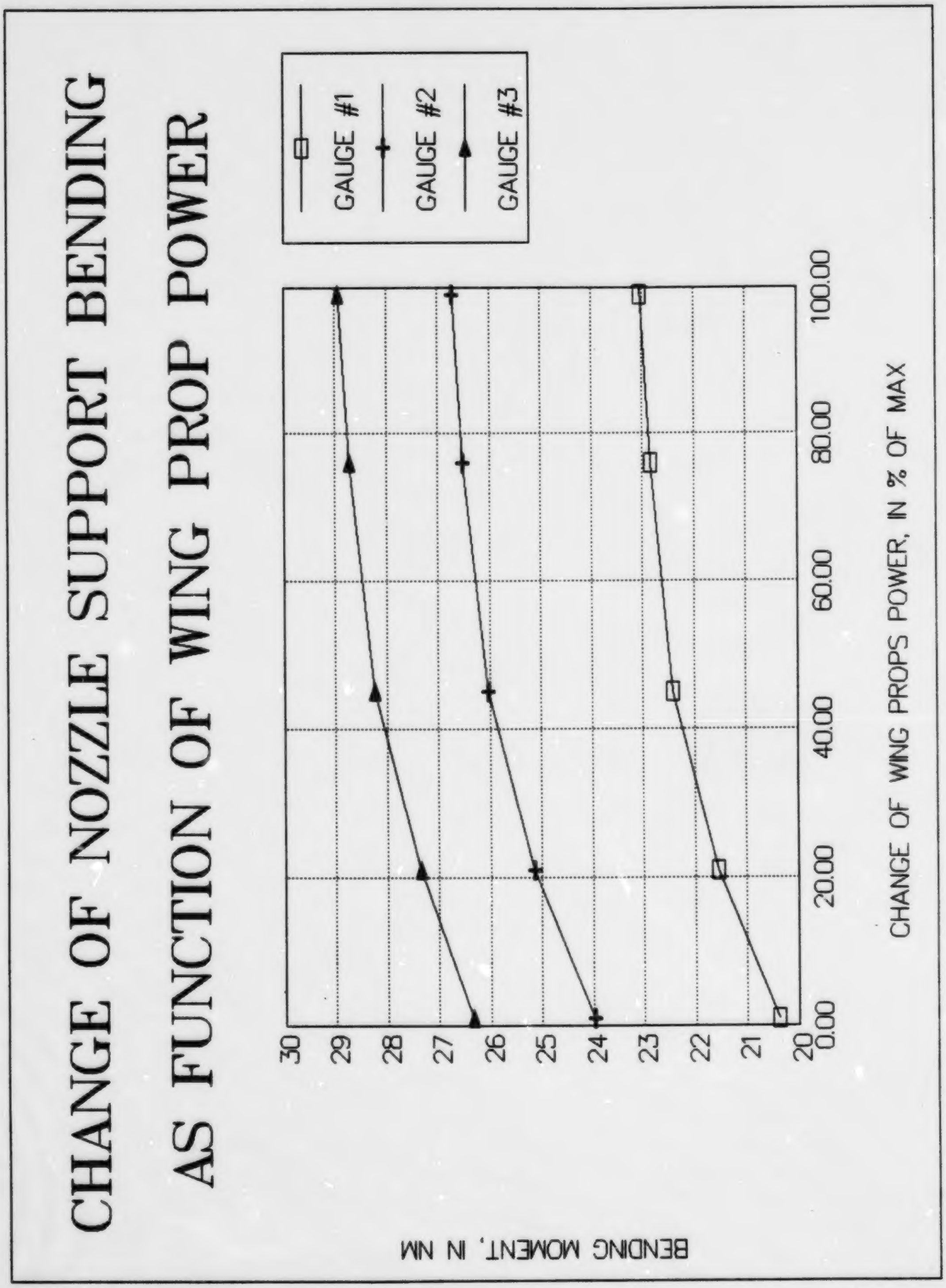


Figure 10.2

## CHANGE OF NOZZLE SUPPORT BENDING

## AS FUNCTION OF WING PROPS POWER LEVEL





CHANGE OF NOZZLE SUPPORT BENDING AS FUNCTION OF WING PROP POWER

Figure 10.4

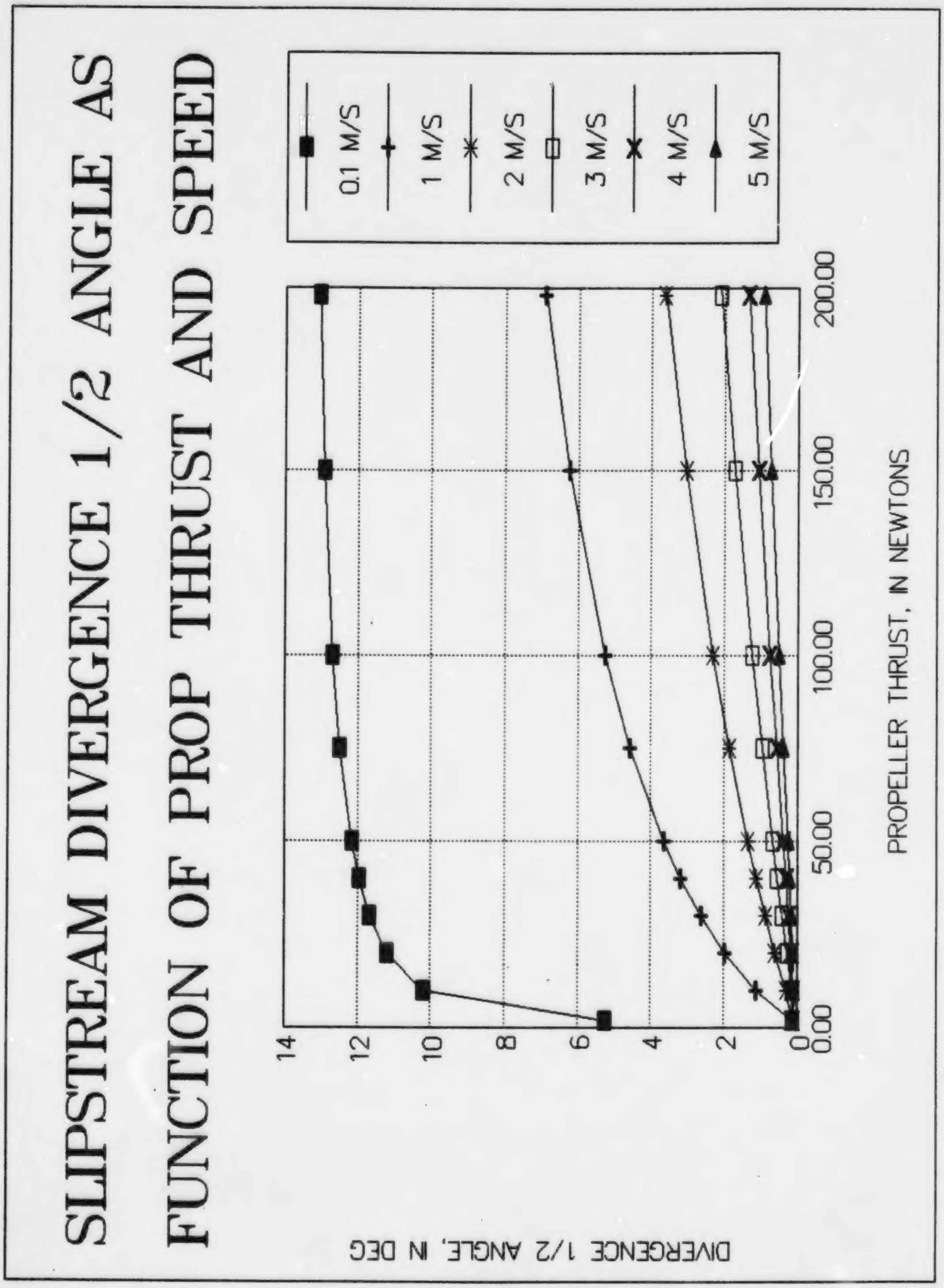
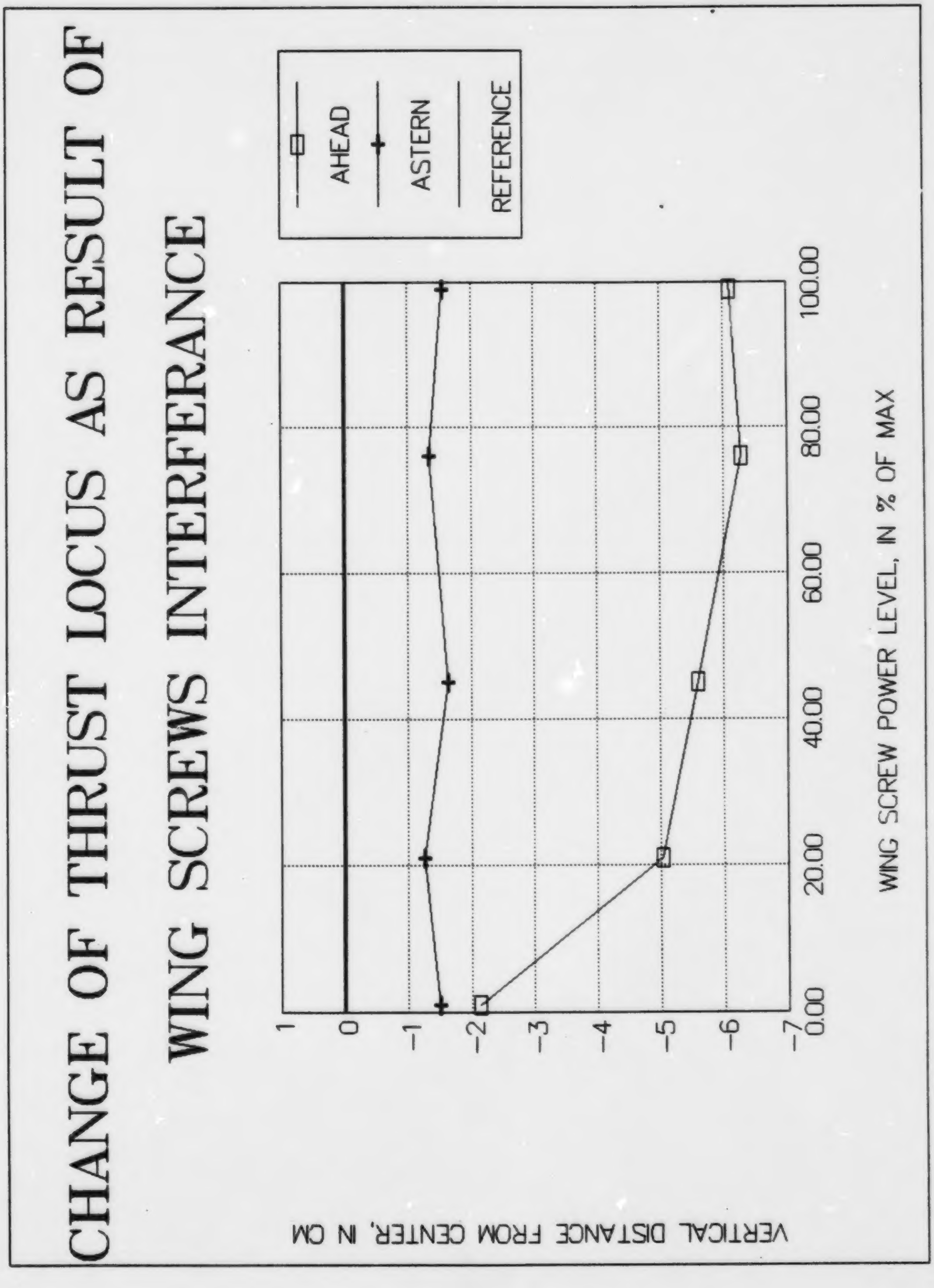
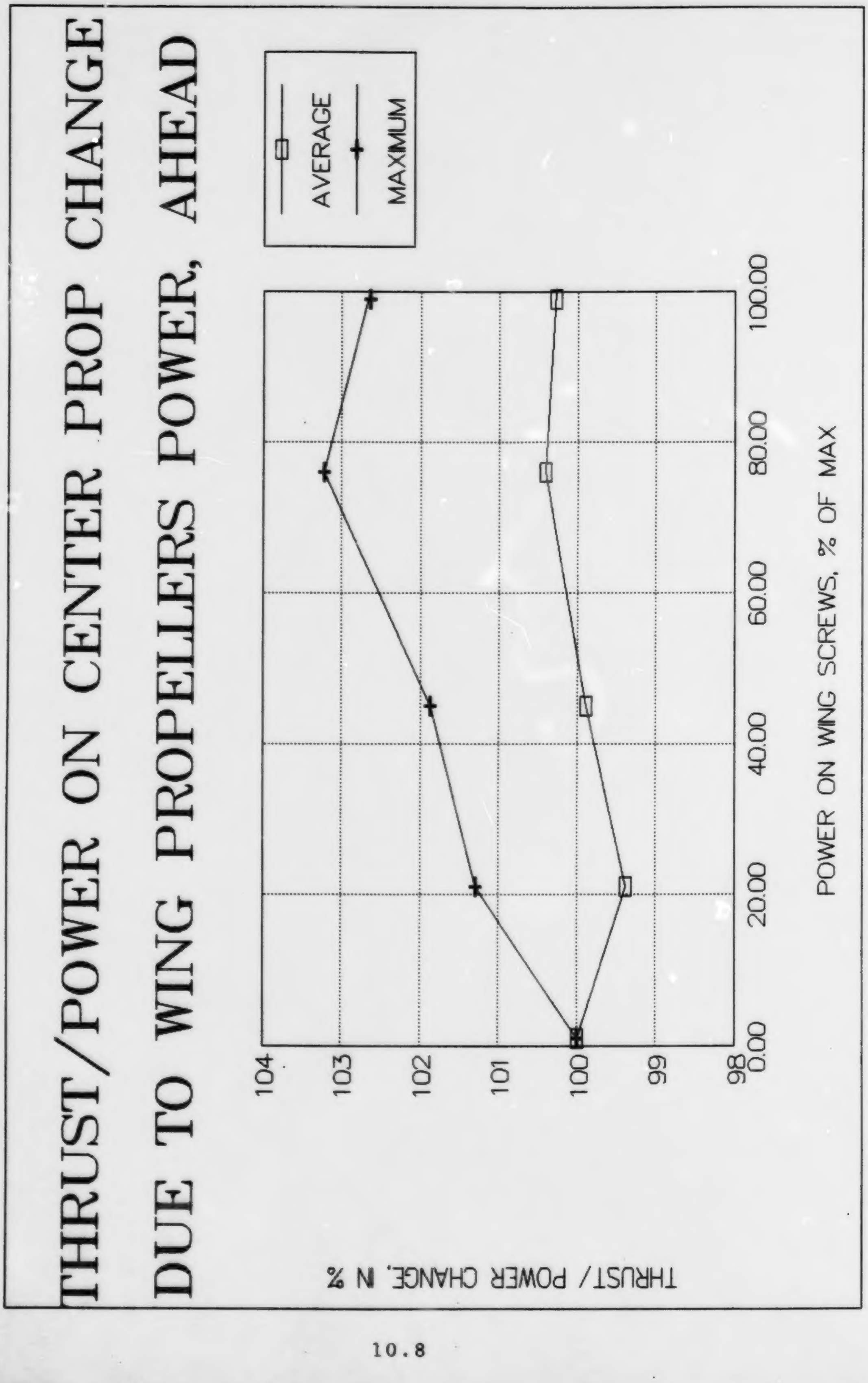

SLIPSTREAM DIVERGENCE 1/2 ANGLE AS
FUNCTION OF PROP THRUST AND SPEED
0.1 M/S
1 M/S
2 M/S
3 M/S
4 M/S
5 M/S
DIVERGENCE 1/2 ANGLE, IN DEG
0
2
4
6
8
10
12
14
0.00
50.00
100.00
150.00
200.00
PROPELLER THRUST, IN NEWTONS

Figure 10.5


CHANGE OF THRUST LOCUS AS RESULT OF
WING SCREWS INTERFERANCE
AHEAD
ASTERN
REFERENCE
1
0
−1
−2
−3
−4
−5
−6
−7
0.00
20.00
40.00
60.00
80.00
100.00
VERTICAL DISTANCE FROM CENTER, IN CM
WING SCREW POWER LEVEL, IN % OF MAX



THRUST/POWER ON CENTER PROP CHANGE DUE TO WING PROPELLERS POWER, AHEAD

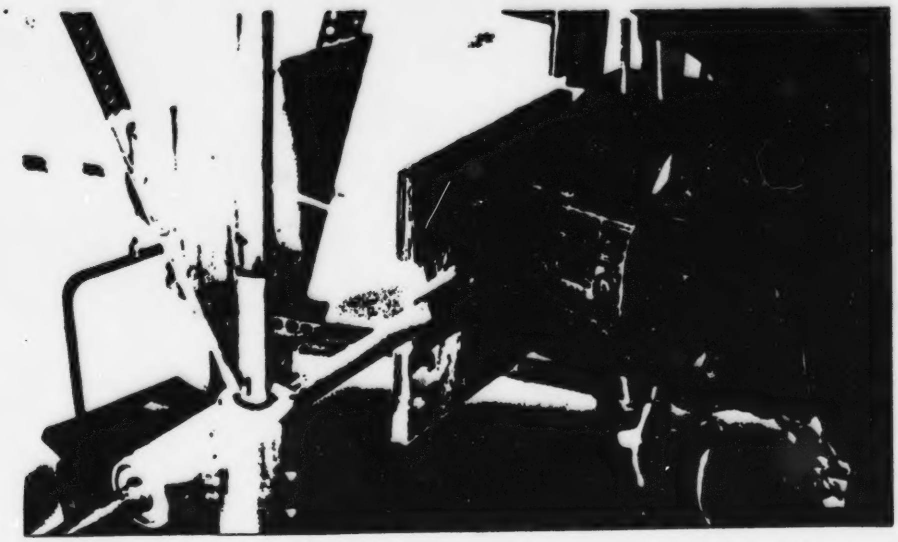


TABLE 10.2

WING PROPELLER INTERFERANCE SUMMARY

| RUN | CENTER SPEED RPS | THRUST CORR'D N | TORQUE CORR'D NM | POWER NM/S | PORT SHAFT SPEED RPS | PORT SHAFT POWER % | STBD SHAFT SPEED RPS | STBD SHAFT POWER % | PROP+NOZZLE SYSTEM THRUST, N 1-2 | PROP+NOZZLE SYSTEM THRUST, N 2-3 | PROP+NOZZLE SYSTEM THRUST, N 3-1 | THRUST/POWER 1 - 2 S/M | THRUST/POWER 1-2 KG/HP | THRUST/POWER 2-3 KG/HP | THRUST/POWER 3-1 KG/HP | AVG N | AUGMENT % AVG | AUGMENT % MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 0.00 | ZERO CHECK | | | 0.00 | 0 | 0.00 | 0 | | | | | | | | | | |
| | | BOLLARD AHEAD | | | | | | | | | | | | | | | | |
| 57 | 7.98 | 113.87 | 7.21 | 362 | 0.34 | 0 | 0.09 | 0 | 249.30 | 235.30 | 242.30 | 0.67 | 13.04 | 12.31 | 12.68 | 12.68 | 100.00 | 100.00 |
| | 7.98 | 111.97 | 7.06 | 354 | 4.74 | 21 | 4.67 | 21 | 247.40 | 224.40 | 235.90 | 0.68 | 13.21 | 11.98 | 12.60 | 12.60 | 99.38 | 101.30 |
| | 7.98 | 112.57 | 7.08 | 355 | 6.61 | 45 | 6.89 | 45 | 249.50 | 226.00 | 237.75 | 0.69 | 13.29 | 12.04 | 12.66 | 12.66 | 99.88 | 101.87 |
| | 7.98 | 112.17 | 7.06 | 354 | 7.99 | 76 | 8.08 | 76 | 252.10 | 224.60 | 238.35 | 0.70 | 13.46 | 11.99 | 12.73 | 12.73 | 100.41 | 103.22 |
| | 7.98 | 113.67 | 7.13 | 357 | 8.71 | 100 | 8.74 | 100 | 253.10 | 227.60 | 240.35 | 0.69 | 13.39 | 12.04 | 12.71 | 12.71 | 100.28 | 102.64 |
| | | BOLLARD ASTERN | | | | | | | | | | | | | | | | |
| 58 | (8.41) | (146.03) | (9.58) | 506 | 0.00 | 0 | 0.00 | 0 | (265.10) | (256.10) | (260.60) | (0.53) | (10.32) | (9.97) | (10.15) | (10.15) | 100.00 | 100.00 |
| | (8.41) | (145.93) | (10.10) | 534 | (4.47) | 21 | (4.71) | 21 | (264.50) | (253.00) | (258.75) | (0.50) | (9.76) | (9.33) | (9.55) | (9.55) | 94.09 | 94.55 |
| | (8.41) | (145.93) | (10.12) | 535 | (6.66) | 47 | (7.03) | 47 | (263.00) | (252.00) | (257.50) | (0.50) | (9.68) | (9.28) | (9.48) | (9.48) | 93.45 | 93.82 |
| | (8.41) | (145.33) | (10.06) | 532 | (7.87) | 76 | (8.13) | 76 | (263.40) | (250.40) | (256.90) | (0.50) | (9.76) | (9.28) | (9.52) | (9.52) | 93.80 | 94.54 |
| | (8.41) | (145.93) | (10.10) | 534 | (8.64) | 100 | (8.73) | 100 | (266.50) | (250.50) | (258.50) | (0.51) | (9.83 | | | | | |

## *11. BLOCKAGE TESTS RESULTS*

### *11.1. Objectives*

*The objective of this test series was to establish the influence of blockage on propulsion loads and to determine the suction forces acting on ice blocks approaching the nozzle.*

### *11.2. Test setup*

*The test setup consisted of the instrumented model (same instrumentation as for the overload tests) and the suction apparatus device. Figure 11.1 shows the apparatus. Its instrumentation consisted of the bending and torsional gauges, which were calibrated with the known loads placed at the middle of the simulated ice block.*

### *11.3. Method used*

*The model was towed by the carriage at predetermined speeds ahead and astern and the forces on the propeller, model, nozzle and suction apparatus were measured. Revolutions of the centerline shaft were varied stepwise from zero to approximately 100%, in four or five steps. Mean values for each step were recorded, corrected for the zero offsets, tabulated and presented in graphical form in this chapter.*

*Then a suction device was placed in one of the eight positions (see table below) and secured to the model. When placed directly in front or at the back of the nozzle, the apparatus was touching the ring. Consequently the nozzle forces were combinations of nozzle hydrodynamic thrust and a part of the suction apparatus force. The other part (very small one) was carried by the apparatus support foundation secured to the model.*

*The schematic of the suction apparatus placement is shown in Figure 11.2.*

*The geometric configurations of the suction device are presented in Table 11.1*

*The resulting forces were then compared with the forces from the overload tests without the blockage.*

TABLE 11.1

GEOMETRIC CONFIGURATIONS OF BLOCKAGE TESTS

| velocity knots, f.s. | position | area blocked |
|---|---|---|
| +0, 2, 5, 15 | middle fore | 47% |
| | top fore | 20% |
| | bottom fore | 23% |
| -0, -2, | middle aft | |
| | top aft | |
| | bottom aft | |
| | middle 5 cm, 10 cm ahead of the nozzle | |

## 11.4. Results.

Table 11.2 summarizes the results of the tests. Altogether 28 tests were conducted with simulated blockage of the nozzle. Except for test #3, all tests were conducted with the centerline propeller operating only. For comparison purposes, the simulated ice block steady state drag was also determined and the results are presented in the paragraph 11.9.

### 11.4.1 Bollard ahead/3shafts/mid fore blocked

Figure 11.3 shows the propulsion forces in this condition. The following changes are apparent when compared to the overload tests without blockage. These changes are common to most of the tested conditions.
(For the same RPS and speed of towing).

Torque increased
Nozzle thrust decreased and became negative
Propeller thrust increased
Total thrust (nozzle and prop) decreased, and
Tow pull decreased.

In addition, severe vibrations of the centerline shaft took place.

These "symptoms of blockage" are completely analogous with those observed in the full scale.

It should be noted however, that the results of the simulated *blockage may be more severe than those observed in full scale due to the following factors:*

> *perfect fit of flat ice block closing nozzle mouth,*
> *constant RPS supply of power to the propeller,*
> *prevention of ice block sliding off the nozzle.*

*It is interesting to note that in this particular condition the increase of RPS does not lead to a significant increase of the system (nozzle and propeller) thrust. This is due to the propeller thrust being offset by the ice block drag pushing on the nozzle.*

### *11.4.2 Bollard ahead/one shaft/ mid fore blocked*

*Figure 11.4 shows the results of this test. It should be noted that the total thrust of the system increased significantly with RPS when compared with the previous case. This is because, in the previous tests, the wing propeller adjacent to the blocking piece was actually pushing it against the nozzle, thus decreasing nozzle push. Another characteristic, also common to all the tests is apparent:*

> *Tow rope pull is less than the system thrust.*

*This is because of part of the drag of the blocking piece, being transferred to the apparatus foundation attached to the ship, and change of the thrust deduction factor due to the change of flow conditions around the propulsor.*

### *11.4.3 Two knots ahead/ middle fore blocked*

*Figure 11.5 shows the forces acting on the system. In comparison to the bollard condition, there is a small decrease of the torque of the propeller, increase of the negative nozzle thrust and decrease of the tow rope pull.*

### *11.4.4. Five knots ahead/ middle fore blocked*

*Figure 11.6 shows this condition. While the torque and thrust of the propeller remain unchanged from the previous condition, further decrease of the nozzle thrust is evident. This is due to the surrounding water drag pushing on the blocking piece resulting in further deterioration of the nozzle hydrodynamic condition.*

### *11.4.5. Fifteen knots ahead/ middle fore blocked*

*Figure 11.7 shows the forces on the system. Again, a small decrease of the propeller torque and thrust is apparent (water* *speed inside the nozzle was not very dependent on the ship velocity in blockage condition). A drastic drag increase of the blocking piece resulted in the high negative nozzle pull and corresponding negative tow pull. Note that the nozzle negative pull and the tow pull in this condition are little dependent on the RPS, as it is governed primarily by the speed of the surrounding water, not by the suction of the propeller. At this speed, the negative tow pull (hull drag and nozzle drag) is twice the combined bollard push of the propeller and nozzle.*

### *11.4.6. Bollard astern/ middle aft blocked*

*In this and slow speed astern condition, illustrated in Figure 11.8, the following features are apparent when compared with the unblocked condition:*

*increase of the torque developed by the propellers*
*increase of the propeller thrust*
*nozzle astern thrust changed to the ahead one*
*slight increase of the tow pull astern.*

*It is interesting to note that the increase of RPS increases the nozzle ahead thrust, which is caused by the block resting on the nozzle exit and being sucked in by the propeller.*

### *11.4.7 Bollard astern/ top blocked.*

*This condition is illustrated in Figure 11.9. One significant change from the previous one is apparent:*

*Astern thrust of the propeller is reduced, however total astern tow pull is increased. This proves, that in spite of the reduced total thrust, the reduced area of the blockage lead to the decrease of the suction force and the increase of the astern tow pull.*

*Inspection of this and subsequent Figures shows the presence of a nozzle thrust "hump" at approximately 50% of rated RPS, where the nozzle reaches its maximum thrust astern. Below this RPS the nozzle thrust decreases to zero with RPS and above the 50% mark, the disturbance of the flow and suction of piece increase again, thus reducing the astern thrust.*

### *11.4.8 Two knots astern/ top blocked.*

*Figure 11.10 shows the results of this test. The nozzle does not produce any significant thrust, while the propeller absorbs large torque and produces 50% of the ahead thrust astern. Tow pull is directed astern, and is approximately 50% of the combined thrust* *of the nozzle and propeller.*

*11.4.9. Two knots ahead/ top blocked.*

*Figure 11.11 shows this condition. As before, although less area is blocked by the simulated ice, significant loss of propeller thrust and some loss of torque is apparent. As a result of this, the net tow rope pull is approx 2/3 of the total thrust produced.*

*11.4.10 Bollard ahead/ top blocked.*

*This condition, illustrated in Figure 11.12 shows the improvements of the propeller and nozzle thrust when compared to the middle part blockage condition. The tow pull improved significantly, almost 100% due to the reduced blockage area and subsequent suction.*

*11.4.11 Bollard ahead/ bottom blocked.*

*This condition is very similar to the one for the top blockage.*

*As Figure 11.13 shows, the nozzle trust improved little, while the propeller torque and thrust remain increased from the no-blockage condition. The tow pull dropped.*

*11.4.12 Two knots ahead/ bottom blocked.*

*A significant increase of thrust and torque over the previous condition is shown in Figure 11.14. Nevertheless the tow pull remains low, at the same level as before. Nozzle thrust is nil.*

*11.4.13 Bollard astern/ bottom blocked.*

*This condition is very similar to the one of the blockage of the upper part of the nozzle. Figure 11.15 shows the tow pull as more than 50% of the total thrust developed.*

*11.4.14 Two knots astern/ bottom blocked.*

*Figure 11.16 shows the result of this test. The forces are very similar to the previous case, with large overload of the propeller and nozzle thrust showing the characteristic "hump."*

*11.4.15 Two knots astern/ middle aft blocked.*

*In spite of the large astern power absorbed by the propeller, the tow pull remains low. The propeller develops a large astern push, while nozzle net pull remains ahead. Figure 11.17 shows this condition.*

*11.4.16 Power ahead/ block 5cm and 10cm ahead of the nozzle.*

*This is the clear cut condition, as the blocking piece does not touch the nozzle, and separation of nozzle thrust and blocking piece pull can be established.*
*Figure 11.18 shows the test results for the bollard ahead and Figure 11.19 for two knots ahead, 5cm (0.75m full scale) distance of the piece from nozzle mouth.*

*Following observations are made:*

*Nozzle develops ahead thrust.*
*The propeller still is overloaded and produces more thrust than in no-blockage condition. The total pull of the propeller and nozzle is near 100% of the nominal one, but the tow pull remains low, as the suction device develops a high astern force. Thrust deduction factor remains large.*
*At two knots condition, the total thrust and torque of the system drops down when compared with the bollard condition, thus showing the relief of the blockage severity due to the increase of the inflow of water into the propulsor.*

*Figure 11.20 show the results for the bollard ahead and Figure 11.21 for two knots ahead and the blocking device placed 10cm (1.5m full scale) in front of the nozzle.*

*The nozzle and propeller thrusts are increased while the torque is near the nominal. The total pull is near the nominal one, showing the thrust deduction of 0.22 at MCR condition.*
*As before, at 2 knots ahead, there is a drop of the thrust and system's pull, with little change in torque.*

*Table 11.3 shows the summary of the blockage tests arranged blockage condition-wise, for the constant RPS.*

*Figures 11.22 to 11.40 compare the blockage severity for the different blockage and ship conditions. Below, an analysis of the results of this comparison is given:*

### ***Bollard ahead/nozzle thrust (Fig 11.22)***

*In the no-blockage condition the thrust of the nozzle is 65% of the total thrust of the system. This thrust drops drastically to 30% when the block is placed 5cm in front of the nozzle, in the middle position. Further drop is occurring when the device is placed at the bottom of the nozzle touching it. The severity of the thrust drop is summarized in TABLE 11.4, for the centerline shaft operating only.*

*It is interesting to note, that in the blocked condition the nozzle thrust is not as sensitive to RPS as in the non-blocked condition.*
*Except for the middle blockage conditions, the nozzle develops the positive thrust in the whole range of RPS.*

*TABLE 11.4*

*Change of the nozzle thrust during the simulated blockage conditions. Bollard ahead*

| *condition* | *nozzle thrust, % of 232.5 N* |
|---|---|
| *10 cm ahead* | *75* |
| ***no blockage*** | ***65*** |
| *5 cm ahead, middle* | *30* |
| *bottom blocked* | *17* |
| *top blocked* | *10* |
| *middle blocked* | *-16* |
| *middle blocked/3 shafts* | *-50* |

*The unexpected increase of the nozzle thrust when the device is placed 10cm ahead of the nozzle mouth is evident.*
*The middle blockage condition is, as expected, the worst one. Doubling of the nozzle drag results when the all three shafts are working. This is because the slipstream from the stbd propeller was pressing on the blocking device touching the nozzle.*

### *Bollard ahead/propeller thrust (Fig 11.23)*

*For all blockage conditions, the propeller thrust increases significantly over the no-blockage condition. The highest increase is 5 cm ahead condition. The 10cm ahead condition shows effectively no propeller thrust change from the non-blocked condition. In all blockage conditions, the propeller thrust is strongly dependent on the RPS. The increase of the propeller thrust can be prioritized as follows:*

| | |
|---|---|
| *largest increase* | *5cm ahead* |
| | *bottom blocked* |
| | *top blocked* |
| | *middle blocked* |
| *no increase* | *10 cm ahead* |
| ***no increase*** | ***no blockage*** |

### *Bollard ahead/ total thrust (Fig 11.24)*

*The total thrust of the system is higher than in the non-blockage condition in only one case - 10cm ahead. All other conditions show the decrease of the thrust, at a higher level of RPS.*
*The lowest total thrust of the system occurs when the middle of the nozzle is blocked. At that condition, the system develops only 37% of the nominal thrust. The bottom blocked condition is the least severe from the ones touching the nozzle. At 50% of MCR RPS, there is an augment of the total thrust for the conditions of 5 and 10cm ahead.*

**Bollard ahead/power absorbed (Fig 11.25)**

*The power absorbed during the blockage condition rises, for all the cases except 10 cm distance 100% RPS. The largest increase is for the 5cm ahead distance. The increase is the largest at RPS range 80% to 90%. The least increase of power occurred at 10 cm distance; the next at the top blocked position.*

**Bollard ahead/ Tow pull/power absorbed (Fig 11.26)**

*This indicator of the overall efficacy of the system is the highest for the device placed 10cm ahead of the nozzle mouth. When compared with the non-blockage condition (see Chapter 9) the 10cm distance condition yields higher efficacy than in unblocked condition at full RPS, and lower at lower RPS. All other blockage conditions give much lower efficacy than in the unblocked condition. Again, the lowest efficacy number is for the middle blocked condition. The least drop occurs for the top blockage condition (from 82% to 43%, which is nearly the 1/2)*

*The dependence on RPS is not very strong in 80% to 100% RPS range.*

**Bollard ahead/tow pull/total thrust (Fig 11.27)**

*This indicator of the thrust deduction factor dropped from the no-blockage condition of 0.82 at 100% RPS to 0.41 in the 5cm distance case. This ratio is not strongly dependent on RPS. The least affected conditions are the 10 cm distance and the top blocked condition (indicator is approx 0.65).*

**Bollard ahead/shaft torque (Figure 11.28)**

*The shaft torque increased for all of the blockage conditions except 10cm distance/100% RPS. The least increase is that and the top blocked condition. The largest increase is for the 5cm distance condition (some 15% increase). The RPS range from 70% to 90% show the largest increase. The torque dependence on RPS in the blocked condition is more linear than in the unblocked condition.*

**Bollard ahead/tow pull (Fig 11.29)**

*The tow pull for the condition 10 cm distance is slightly higher than in the non-blocked condition at 100% RPS and much lower at lower RPS. The worst condition occurs when the middle is blocked (a drop from 78% to 25% of 232.5 N). Other conditions register the pull of approximately 40% of the 232.5N. The linear* *dependence on RPS is apparent.*

### Middle blocked/Total thrust/ship speed (Fig 11.30)

*A large drop of the total thrust with the increase of ship speed is apparent. While for the 15 knots non blocked condition the total thrust of the system was 15% of 232.5N, it drops to -20% in the middle blocked condition. The difference between the bollard and 5kn ahead is not very large. Thrust/power relationship is shown in Figure 11.31 for the ahead speed and 90% RPS. The drop of this ratio with the speed is non-linear, for both blocked and non-blocked condition. The largest drop is for the 3 shafts operating condition.*

### Bollard astern/nozzle thrust (Fig 11.32)

*The least severe condition for the nozzle thrust astern was with the middle blocked, for the higher range of RPS. In this condition the nozzle thrust dropped slightly to 35% from the 40% in the non-blocked condition. Other blockage conditions lead to the thrust drop to 10% of the nominal thrust ahead (fourfold).*

### Bollard astern/Propeller thrust (Fig 11.33)

*Propeller thrust increased slightly (approx 5%) for the center blocked condition when compared with the non-blocked condition. Other conditions lead to the lowering of the propeller thrust, by approximately 15%.*

### Bollard astern/total thrust (Fig 11.34)

*The total thrust of the system astern dropped only slightly (less than 3%) in the middle blocked condition when compared with the non blocked condition. However, both top and bottom blockage resulted in a severe drop of total astern thrust (less than half).*

### Bollard astern/torque (Fig 11.35)

*The torque rose for all of the conditions. An increase of less than 20% of the torque took place for the middle blocked condition, and approximately half of that in the other conditions.*

### Bollard astern/power developed (Fig 11.36).

*All blockage scenarios lead to the increase of power absorbed. The highest increase was in the middle blocked condition, totaling approximately 24%, at 90% RPS. The least increase took place for the bottom blocked condition. The dependence on the RPS of the power, thrust and torque was very similar in the blocked and non blocked conditions.*

### Bollard astern/tow pull (Fig 11.37).

*The highest tow pull was achieved for the top blocked condition, totaling 40% of the ahead bollard thrust (59% of the total pull astern in the non-blocked condition). Other tow conditions showed slightly poorer performance (35% of the ahead bollard thrust).*

***Bollard astern/ Thrust/power ratio (Fig 11.38)***

*The highest thrust/power ratio was for the top blocked condition. (50%). This ratio decreases rapidly with the increase of the propeller RPS. The lowest ratio is for the middle blocked condition (38%). In the non blocked condition for the 90% RPS this ratio is 1.25.*

***Tow pull/thrust (Fig 11.39)***

*The worst ratio is for the middle blocked condition, averaging 0.35 throughout the whole range of RPS. The highest (0.74) is for the top blocked condition. This ratio is higher than in the non-blocked condition (0.68). However the difference is within the accuracy of the measurements. Little dependence on the RPS of the middle and bottom blocked condition is apparent.*

***Tow pull/power (Fig 11.40)***

*The highest ratio of the tow pull/power delivered is for the bollard condition, top blocked. It totals approx 50%, which compares with the 68% in the non blocked condition at full power. This ratio drops rapidly with the increase of RPS. The lowest ratio was for the Two knots astern, middle blocked condition (20%). In this condition, the ratio increases with the increase of RPS. The ratio drops rapidly with the change of speed from 0 to 2 knots astern, for all of the conditions tested.*

### *11.5 Suction forces measurements.*

*Figure 11.41 shows the suction force acting on the simulated blockage device positionned 5cm ahead of the nozzle mouth, in the bollard and two knots ahead condition. There is a strong nonlinear dependence between the two variables. In the two knots ahead case, the force acting on the block is approximately equal to the propeller thrust. For the bollard condition, it is approximately 75% of the propeller thrust.*

*Figure 11.42 shows the same trend for the 10cm distance, for the bollard and 2 knots ahead. The suction forces are much weaker than in the previous case, but show the same strong nonlinear dependence on the propeller thrust. Again, the suction force is larger for the 2 knots condition than for the bollard condition.*

*Figure 11.43 shows the suction force data for the 2cm and 10cm distances. The strong nonlinear dependence on power is apparent. For the 100% power developed and 5cm distance, the suction force* *developed is 50% of the total thrust of the system, which means that it is approximately equal to the thrust of either propeller or the nozzle. For the 10cm distance the same relationship holds, the forces being approximately 1/3 of those at 5cm distance.*

## *11.6 Nozzle/propeller thrust distribution during the blockage.*

*Figure 11.44 shows the dependence of the nozzle thrust on the propeller thrust, in the bollard, middle blocked condition.*
*A very strong dependence is apparent. As the propeller develops more thrust, the suction forces on the blocking piece are increased proportionally and the nozzle, which has to support the suction and drag forces develops a negative thrust being approximately 1/5 of the propeller thrust.*
*A similar condition exists for the 10 knots ahead speed, when additional drag of the blocking piece has to be carried by the nozzle.*

## *11.7 Miscellaneous observations from the blockage tests*

*1. Blockage condition is analogous to the propeller nozzle system operating in a strong wake, or even in the reversed flow. Considering the latter, the system is operating in the third quadrant (see Figure 11.45), that is, the ship is going astern, but the propeller is turning in the ahead direction. For example, for the attack angle beta = 320 deg we have the following condition:*

*propeller thrust increase*
*propeller torque increase*
*nozzle thrust drop*

*To calculate the corresponding angle for the model tests, we take:*

$$beta = arctan(Va/(0.7*Pi*D*n)) \ldots\ldots\ldots\ldots 11.1$$

*Putting D =0.28m, n =8 rps, we will obtain:*

| | | | | | |
|---|---|---|---|---|---|
| *Va, m/s* | *0* | *- 0.1* | *-0.5* | *-2.0* | *(model scale)* |
| | | *-0.4* | *-1.9* | *-7.7* | *(full scale)* |
| *beta, deg* | *360* | *359* | *354* | *338* | |

*For the particular propeller/nozzle system, the rise of the torque and thrust begins at approximately beta = 340 degrees.*

*That is,*

***the blockage condition corresponds to the propeller/nozzle system** operating in a high wake or even during the astern motion of the ship, while the propeller rotates forward.*

*It is known that such off- design conditions lead to the severe vibrations of the shafting systems, which is also analogous to the blockage situation. Thus this condition can happen on any ship* ***even without going thru the ice field.***

2. *The propeller work was least affected by the blockage condition. It should be noted that the particular model propeller used in the tests had very rounded edge, hence was not very sensitive to the changes in the inflow angle. Exactly profiled fixed pitch propeller would be more sensitive to those changes, and the controllable pitch propeller would be the most sensitive. The adjustments to the angle of water inflow would have been made by the adjustment of the RPM in the fixed pitch case, and by the adjustment of the pitch angle in the case of CPP.*

### *11.8 Vibrations during the blockages.*

*One characteristics of the blockage situation in the full scale (Reference 3,4,5) is the pronounced vibrations of the shaftline components, propeller and the nozzle. The same happened during the model tests. Figure 11.46 shows the typical signals collected during the blockage experiments. The level of vibrations can conveniently be measured by the ratio of the RMS of the signal to the mean value of this signal. The ratio can be expressed as:*

*vibration level = ((X1^2 + X2^2 +....)*n)^0.5/(X1 + X2 +..)..11.2*

*where Xi is the value of the i-th signal and n is the total number od the samples collected.*
*Table 11.5 summarizes the ratios for the following signals:*

*shaft thrust*
*shaft torque*
*nozzle bending moment*

*Figure 11.47 shows the correlations of RPS and the shaft thrust vibration level for different blockage scenarios. The following observations are made:*

1. *In the no-blockage condition the ratio is of the order 6% to 8%, varying little with the RPS.*
2. *For all of the blockage scenarios, the vibration level rose when compared with the non-blocked condition. The highest rise was attributed to the bollard ahead, middle blocked condition, for the high RPS range.*
3. *All of the blockage conditions showed an exponential rise of this ratio with the decrease of the mean thrust level.*

*Figure 11.48 shows the same trends for the torque signal. The following observations are made:*

1. Torque vibration levels are of the same order of magnitude as the thrust vibration levels.
2. The only rise of the torque vibrations occurred for the bollard ahead, middle blocked condition.
3. When the excitation frequency corresponds to the free vibration frequency, the large magnification of vibration levels occur.
4. All, except for the middle blocked, conditions showed decrease of the torque vibration levels in the blockage scenarios.

Figure 11.49 shows the vibration level of the nozzle bending signal (longitudinal vibrations). The following comments are made:

1. The vibration level of the nozzle rises in the blockage situation.
2. The highest vibration level corresponds to the full power, bollard condition with the device placed 5cm ahead of the nozzle. This is because when the device is placed on the nozzle mouth, it dampens the vibrations somewhat.
3. When the distance was 10 cm ahead of the nozzle, nozzle vibrations were of the same amplitude as without the blockage.
4. The level of the nozzle axial vibrations reached over 100%.

Figure 11.50 shows the correlation of the nozzle torsional and longitudinal vibrations during one blockage test. The two modes of vibrations are completely independent. The bending vibrations level is higher than the torsional one, for this particular test.

Figure 11.51 shows the correlation between the shaft thrust vibrations and nozzle axial vibrations. The inverse proportionality is apparent: high thrust vibrations are linked to low nozzle axial vibrations and vice versa.

Figure 11.52 shows the correlation of the thrust versus the torque vibration levels. Again there is no direct relationship between the two variables.

Figure 11.53, 11.54, 11.55 and 11.56 show the free vibrations of the nozzle and the procedure to determine their natural frequency.

## 11.9 Drag on the suction plates

Photos 11.57 and 11.58 show the geometrical configuration of the suction plates. The plates were towed at predetermined speeds in order to establish their steady state drag and to compare it with the suction forces generated by the nozzle/propeller system Table 11.7 summarizes the test results, and Figure 11.57 depicts the drag correlation with speed squared. The correlation is very strong (R =0.996). The drag coefficient is approximately 1.3. The drag can be computed using the following relationship:

*R (N) = 46.26 * V^2.........................11.3.*

*where V is the velocity, in m/s.*

*The suction forces measured during the blockage tests on the plates were, for the distance of 5cm, of the order of 100N. This force corresponds to the drag at the speed of*

*Vd = 1.47 m/s (11 knots full scale)*

*For the suction device placed 10cm forward of the nozzle, the suction force is of the order of 35N. This force corresponds to the drag at the velocity of*

*Vd = 0.87 m/s (6.6 knots full scale)*

*The above computations were done for the vessel in the bollard condition.*

## *11.10 Conclusions from the blockage tests.*

*The following are the main conclusions from the blockage tests:*

*BLOCKAGE CHARACTERISTICS*

*1. Blockage leads to the following (for the constant RPS):*

*increase of the shaft thrust,*
*increase of the shaft torque,*
*decrease of the nozzle thrust,*
*decrease of the total thrust,*
*increase of the power absorbed,*
*decrease of the tow rope pull,*
*increased level of vibration of the nozzle, propeller and shaftline.*

*2. Nozzle blockage corresponds hydrodynamically to the condition when the vessel is moving at a certain speed in open water but the propeller works in a strong wake, that is at much lower speed of advance than the ship (even negative speed of advance), and the propeller rotates in the forward direction.*

*PERFORMANCE OF PROPELLER/NOZZLE IN BLOCKED CONDITION*

*3. The largest nozzle thrust drop was recorded from the +65% in the non-blocked condition to -50% of the total system thrust at the bollard when the middle part of the nozzle was blocked and all three shafts were working. A slight increase of the nozzle thrust was noted when the device was placed some 10cm in front of the nozzle mouth.*

4. The performance indicators, like tow pull/power developed or the total system thrust/power developed dropped with introduction of blockage from approximately 100% to 25% in the middle blocked condition.

5. The most severe blockage condition, in terms of the tow pull/power delivered, occurred when the middle part of the nozzle was blocked. The least severe was when the device was placed 10cm ahead of the nozzle. In terms of the tow pull/power delivered the following is the order of performance:

TABLE 11.6
Summary of the system performance

| PERFORMANCE | CONDITION<br>BOLLARD AHEAD | BOLLARD ASTERN | AREA BLOCKED |
|---|---|---|---|
| best | no blockage | no blockage | 0% |
| | 10 cm distance | | |
| | top blocked | top blocked | 20% |
| | bottom blocked | bottom blocked | 23% |
| | 5 cm distance | | |
| worst | middle blocked | middle blocked | 47% |

6. Wing shafts increase blockage severity, by providing an additional drag force on the blocking piece, which translates into the lower overall nozzle thrust.

7. Vessel speed decreases the total thrust/power delivered ratio substantially in the blocked condition.

8. In the astern condition the effects of the blockage were more moderate than in the ahead condition.

SUCTION FORCES

9. Suction forces on the block placed ahead of the nozzle mouth depend strongly on the propeller thrust.

10. The suction forces decrease with the increase of speed.

11. The suction forces at a piece placed 5 cm ahead of the nozzle are of the same magnitude as the propeller thrust.

12. The forces decrease rapidly with the increase of the distance from the nozzle. Doubling the distance cuts the suction force to approximately 1/3.

13. In the blocked condition, the nozzle develops a small fraction of the propeller thrust, and the nozzle thrust is directed aft (including the suction force).

14. The suction force on the blocking piece at 90% of the power, placed 5 cm ahead of the nozzle mouth, is of the same

*magnitude as the drag on that piece at a velocity of 11 knots.*

### *VIBRATION LEVELS*

15. *The thrust, torque and nozzle vibration levels are significantly increased from the non-blocked condition.*
16. *Shaft longitudinal vibrations are not related to shaft torsional vibrations*
17. *Nozzle axial vibrations are not coupled with the nozzle torsional vibrations.*

Figure 11.1

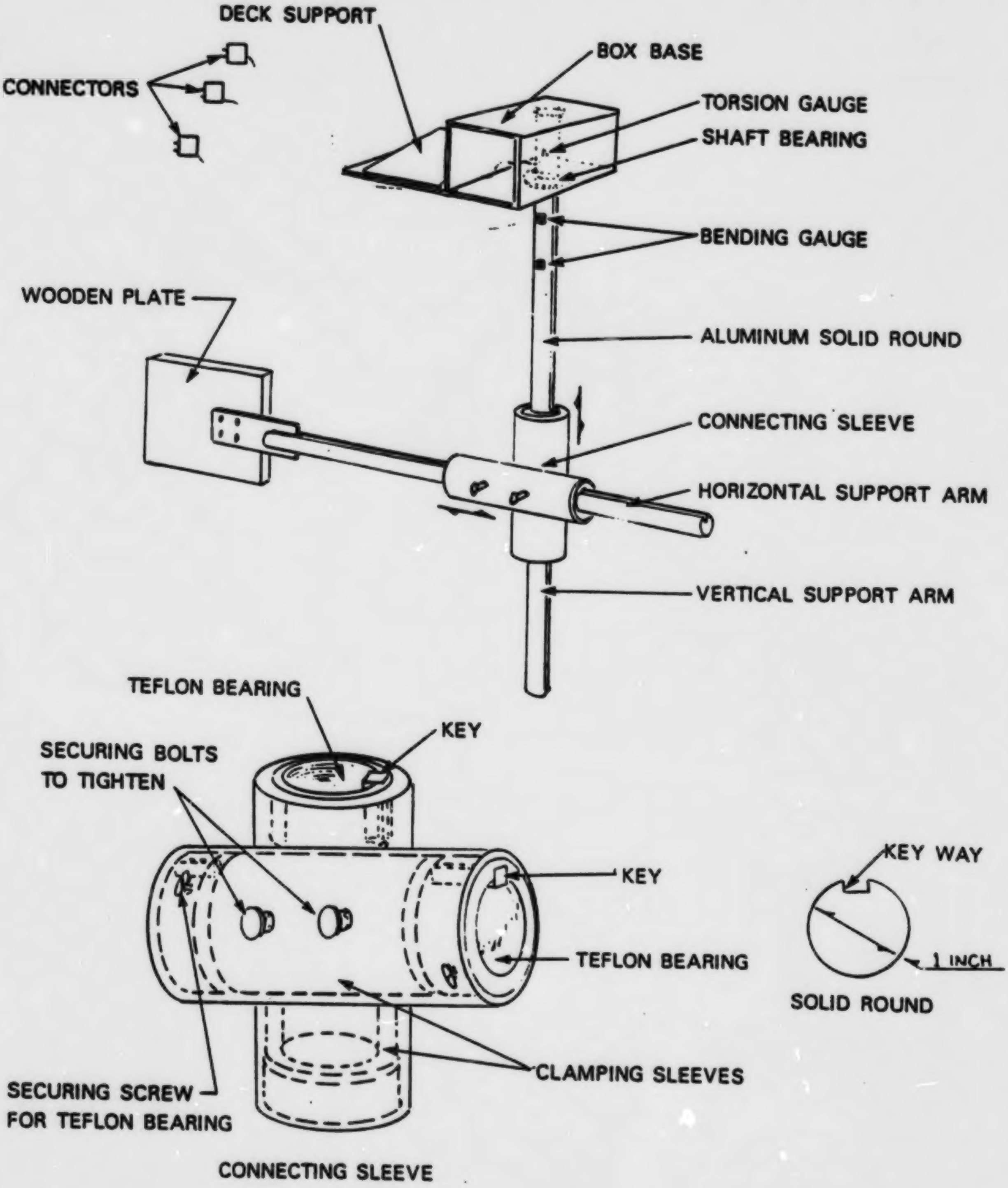
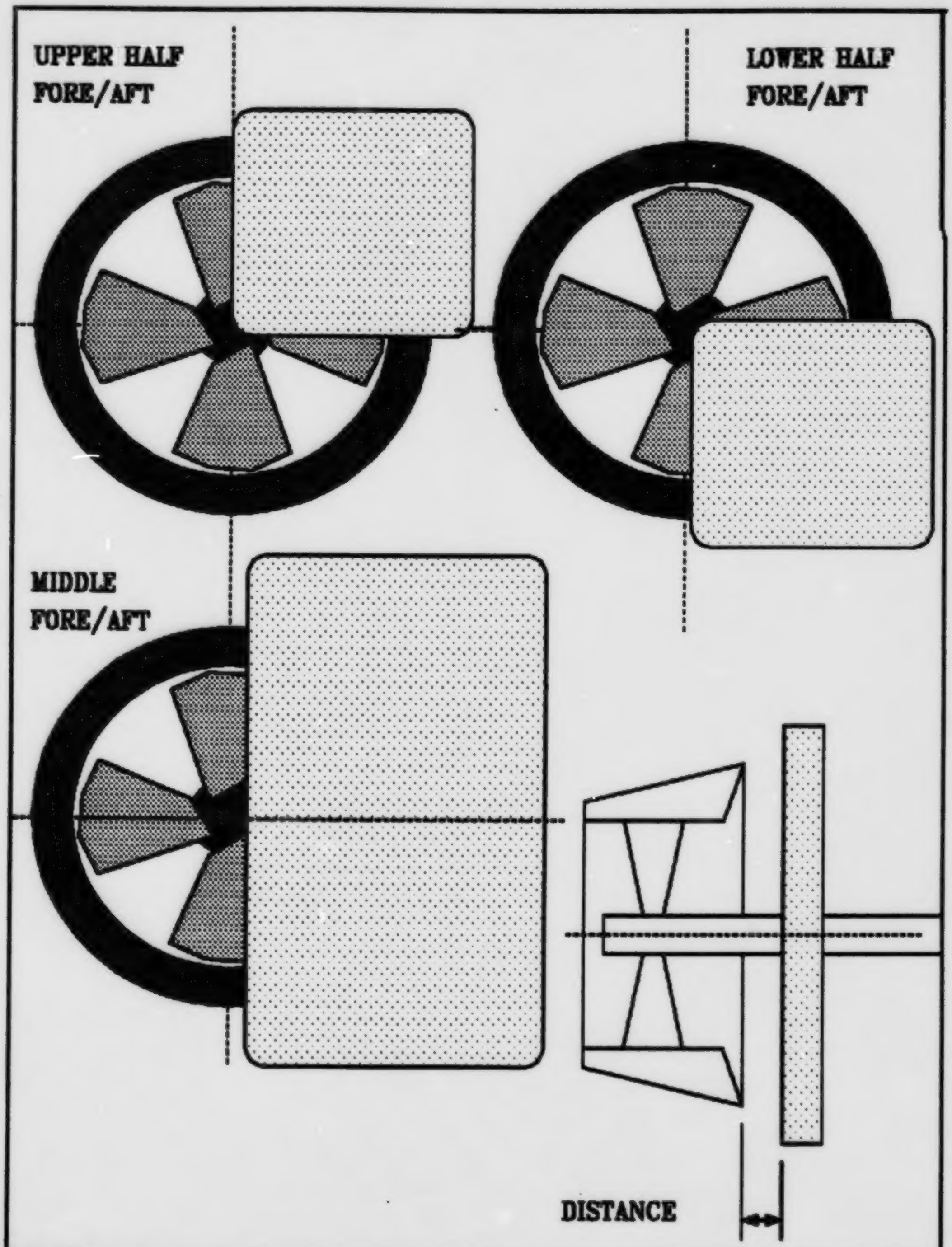


FIGURE Suction Device

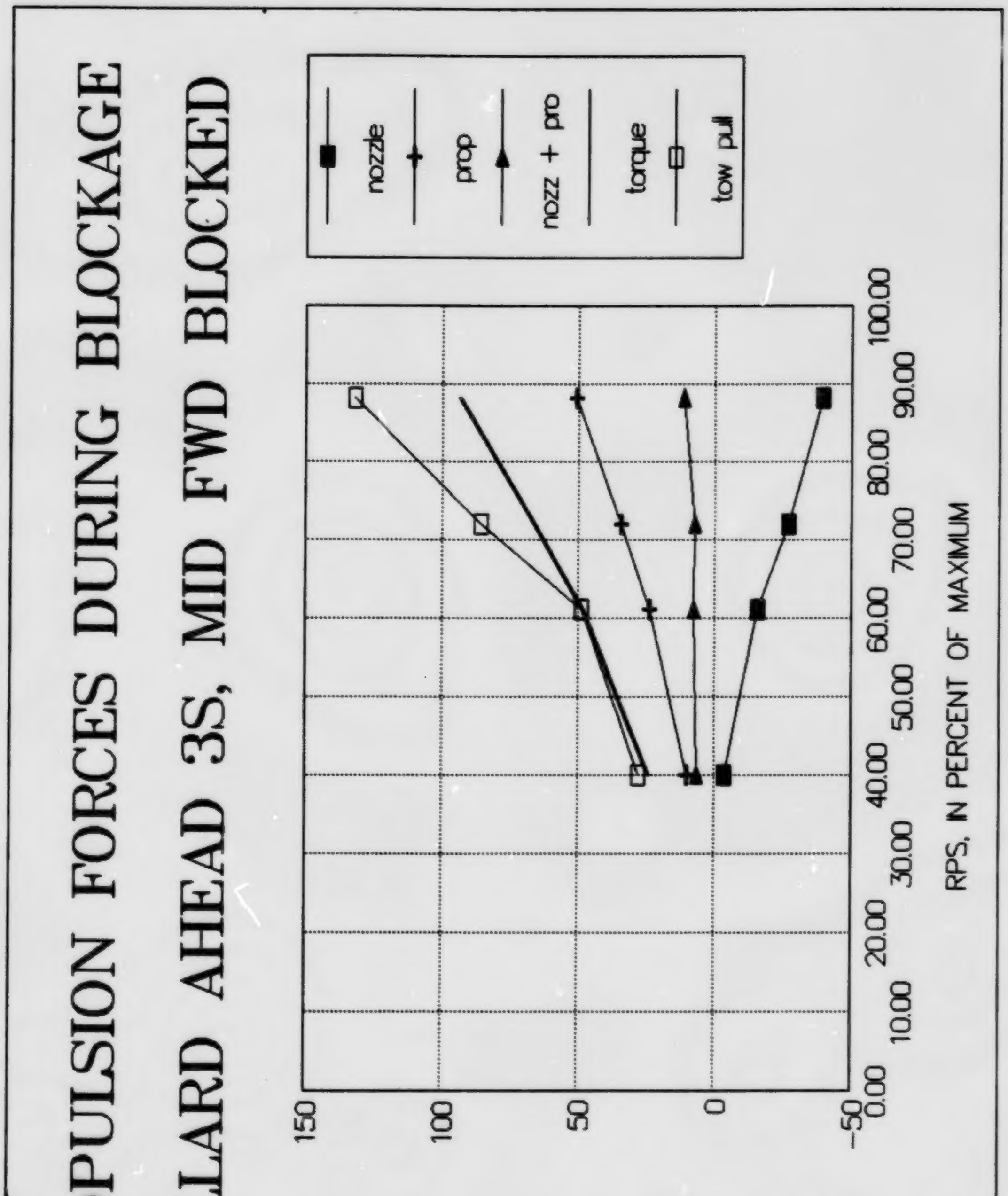


| | | | |
|---|---|---|---|
| FIGURE TITLE: BLOCKAGE ARRANGEMENT | | | |
| PROJECT NAME: ICE FLOW AND BLOCKAGE | | | PROJECT NR: |
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: 11.2 |

## TABLE 11.2
## SUMMARY OF BLOCKAGE TESTS

| % RPS (8=100%) | THRUST IN % OF 232.5 NOZZLE | PROP | TOTAL | TORQUE IN % OF 7.84 | TOW PULL % OF 232.5 | SUCTION FORCE |
|---|---|---|---|---|---|---|
| BOLLARD AHEAD, CENTER ONLY | | | | | | |
| 41.86 | 0.98 | 9.25 | 10.24 | 18.18 | 4.38 | 0.63 |
| 60.55 | (3.06) | 20.96 | 17.91 | 38.89 | 9.54 | 1.34 |
| 71.44 | (5.90) | 29.26 | 23.36 | 57.76 | 13.58 | 1.68 |
| 87.19 | (11.10) | 45.25 | 34.15 | 89.76 | 19.34 | 3.40 |
| BOLLARD AHEAD, ALL SHAFTS | | | | | | |
| 40.05 | (3.75) | 10.16 | 6.41 | 24.29 | 27.87 | 5.75 |
| 61.20 | (15.83) | 23.66 | 7.82 | 48.70 | 48.88 | 6.67 |
| 71.99 | (27.23) | 34.31 | 7.08 | 66.43 | 85.56 | 8.71 |
| 88.20 | (39.49) | 50.84 | 11.35 | 93.33 | 131.90 | 12.26 |
| 2 KNOTS AHEAD, CENTER ONLY | | | | | | |
| 39.74 | 2.34 | 6.83 | 9.17 | 21.10 | 0.51 | 1.77 |
| 63.28 | (5.10) | 21.46 | 16.36 | 47.03 | 5.75 | 2.10 |
| 71.86 | (5.88) | 28.58 | 22.71 | 59.16 | 8.79 | 2.91 |
| 88.22 | (13.68) | 44.86 | 31.18 | 86.68 | 14.18 | 3.71 |
| 5 KNOTS AHEAD, CENTER ONLY | | | | | | |
| 39.86 | (2.76) | 4.53 | 1.78 | 17.64 | (19.34) | 5.72 |
| 62.63 | (7.66) | 19.32 | 11.66 | 44.08 | (18.77) | 6.01 |
| 72.11 | (8.95) | 27.50 | 18.55 | 58.46 | (14.52) | 6.07 |
| 88.95 | (16.26) | 45.46 | 29.20 | 87.28 | (7.05) | 6.33 |
| 15 KNOTS AHEAD, CENTER ONLY | | | | | | |
| 39.69 | (38.20) | (13.02) | (51.22) | (12.59) | (215.00) | 34.37 |
| 68.70 | (42.93) | 7.42 | (35.51) | 27.51 | (206.03) | 31.08 |
| 91.04 | (53.25) | 30.08 | (23.17) | 66.25 | (199.57) | 31.65 |
| BOLLARD ASTERN, CENTER ONLY | | | | | | |
| (40.73) | 3.44 | (11.32) | (7.88) | (11.48) | (5.24) | 0.92 |
| (61.11) | 6.63 | (25.84) | (19.21) | (34.02) | (11.78) | 2.95 |
| (71.89) | 9.62 | (35.84) | (26.22) | (49.44) | (16.41) | 4.28 |
| (91.07) | 17.71 | (58.06) | (40.35) | (81.61) | (26.37) | 5.73 |

```
        (74.94)  (16.41)  (28.64)  (45.05)  (59.77)  (26.00)   (0.74)




        (87.70)  (11.76)  (42.23)  (54.00)  (81.61)  (37.65)   (4.68)
2KN ASTERN, TOP BLOCKAGE

        (10.35)   (0.00)    6.21     6.21    (1.86)    4.94     1.78
        (47.24)    4.11    (6.52)   (2.42)  (23.24)   (1.00)    1.74
        (61.00)    6.75   (15.86)   (9.11)  (38.55)   (6.74)    0.91
        (95.94)   (9.46)  (49.38)  (58.84)  (95.75)  (30.74)   (1.46)
BOLLARD AHEAD BOTTOM BLOCKAGE


         37.11     8.45    13.96    22.41    18.71     5.91    (0.96)
         50.81     8.24    21.19    29.42    31.40    11.24    (1.10)
         84.10    14.47    48.47    62.95    81.79    30.82    (0.43)
2KN AHEAD, BOTTOM BLOCKAGE
          4.00    (0.00)    6.39     6.39     3.46    (3.17)   (2.08)
         43.19    (3.23)   17.52    14.29    23.46     2.80    (1.11)
         67.58    (4.95)   33.51    28.57    53.01    13.29    (1.25)
        101.41    (3.01)   70.41    67.40   117.96    31.96     1.02
[illegible]ARD ASTERN, BOTTOM BLOCKAGE
        (11.13)   (0.00)    7.03     7.03    (1.45)    2.11     1.72
        (47.86)   (4.82)   (6.56)  (11.38)  (23.55)   (7.51)   (1.29)
        (64.63)   (7.63)  (18.34)  (25.97)  (42.88)  (15.95)   (2.55)
        (91.86)  (10.95)  (45.76)  (56.71)  (88.18)  (33.57)   (6.37)
2KN ASTERN, BOTTOM BLOCKAGE
        (10.35)   (0.00)    7.23     7.23    (0.66)    5.76    (0.28)
        (48.81)  (15.83)   (5.39)  (21.22)  (22.37)   (1.18)   (0.50)
        (67.65)  (21.25)  (18.19)  (39.44)  (44.46)   (7.77)   (1.54)
        (98.51)  (12.17)  (49.76)  (61.94)  (97.79)  (25.65)   (5.85)
=======================================================================
```



PROPULSION FORCES DURING BLOCKAGE
BOLLARD AHEAD 3S, MID FWD BLOCKED

Figure 11.4

PROPULSION FORCES DURING BLOCKAGE
BOLLARD AHEAD, MIDDLE FWD BLOCKED

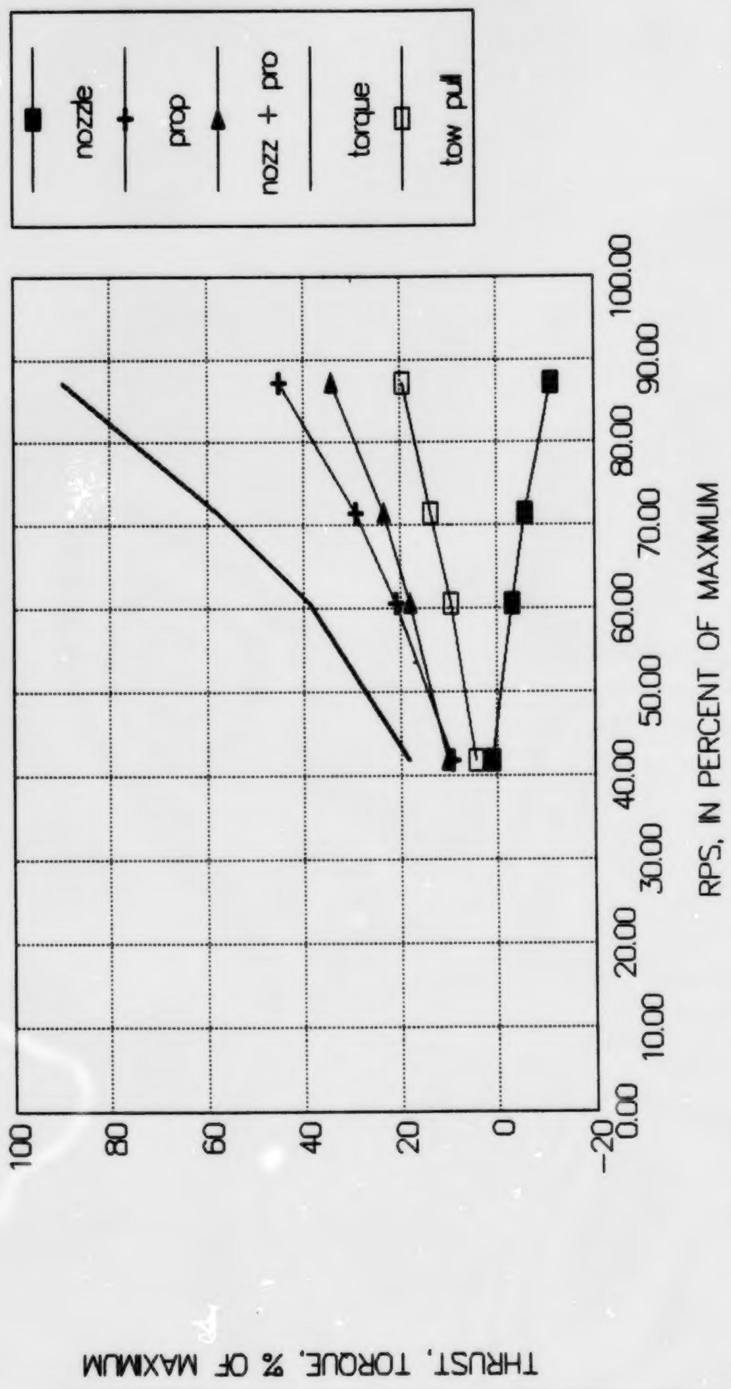


Figure 11.5

PROPULSION FORCES DURING BLOCKAGE
2KN AHEAD, MIDDLE FWD BLOCKED

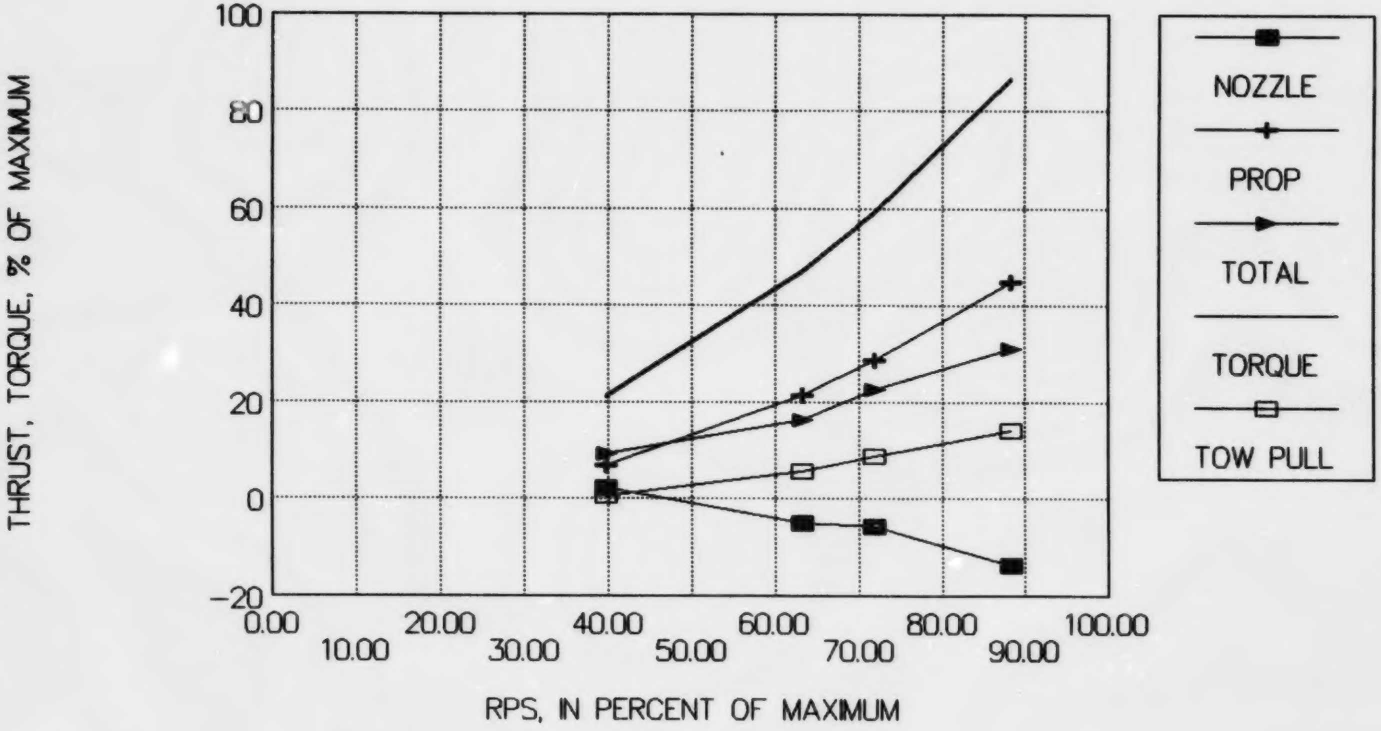
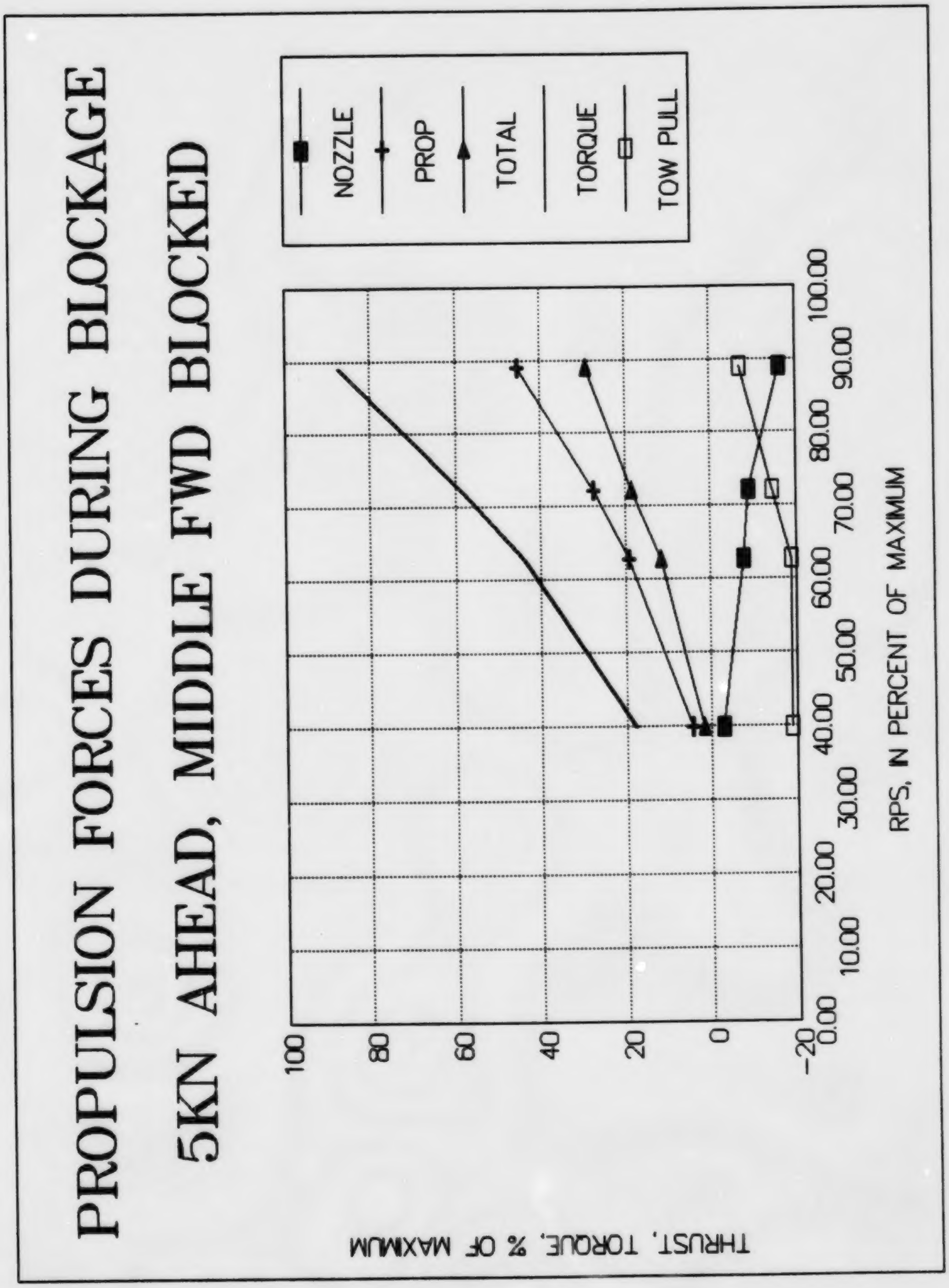


Figure 11.6


PROPULSION FORCES DURING BLOCKAGE

5KN AHEAD, MIDDLE FWD BLOCKED

Figure 11.7

# PROPULSION FORCES DURING BLOCKAGE
# 15 KN AHEAD, MIDDLE FWD BLOCKED

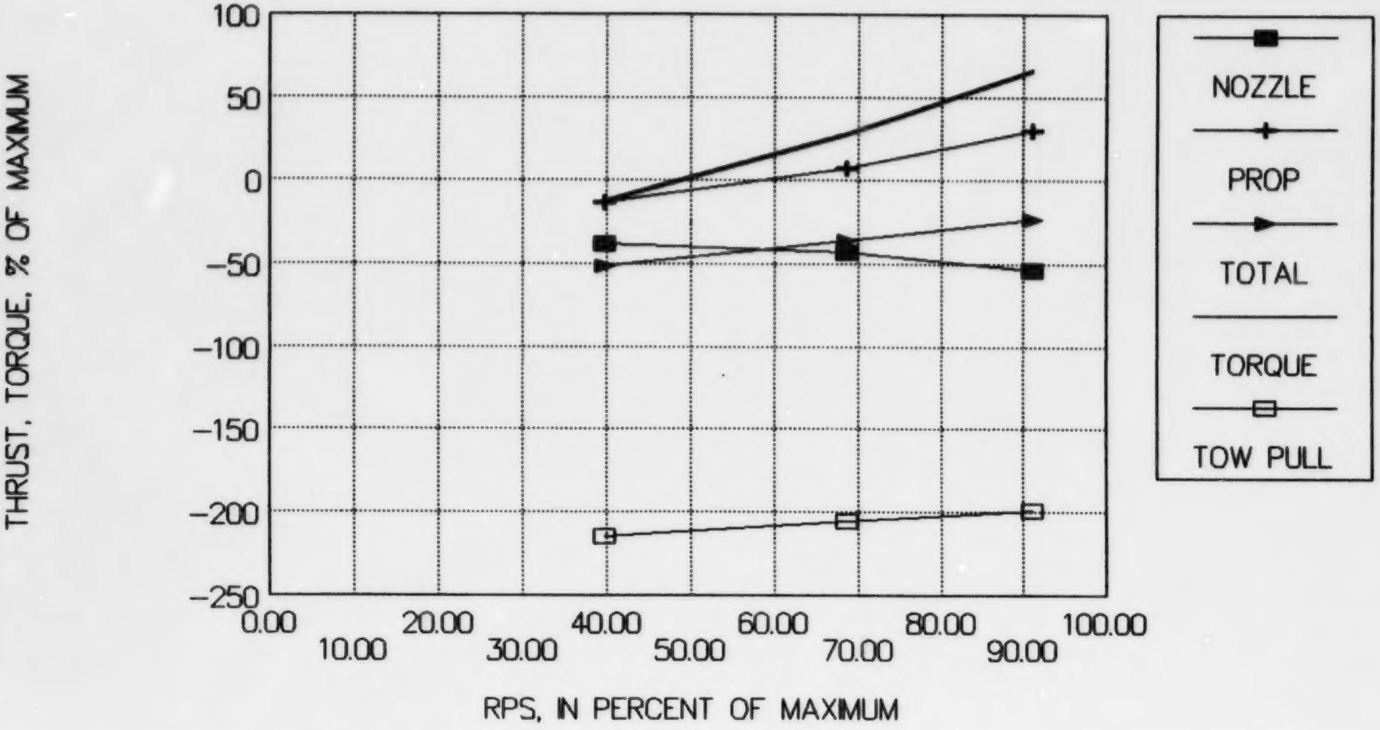
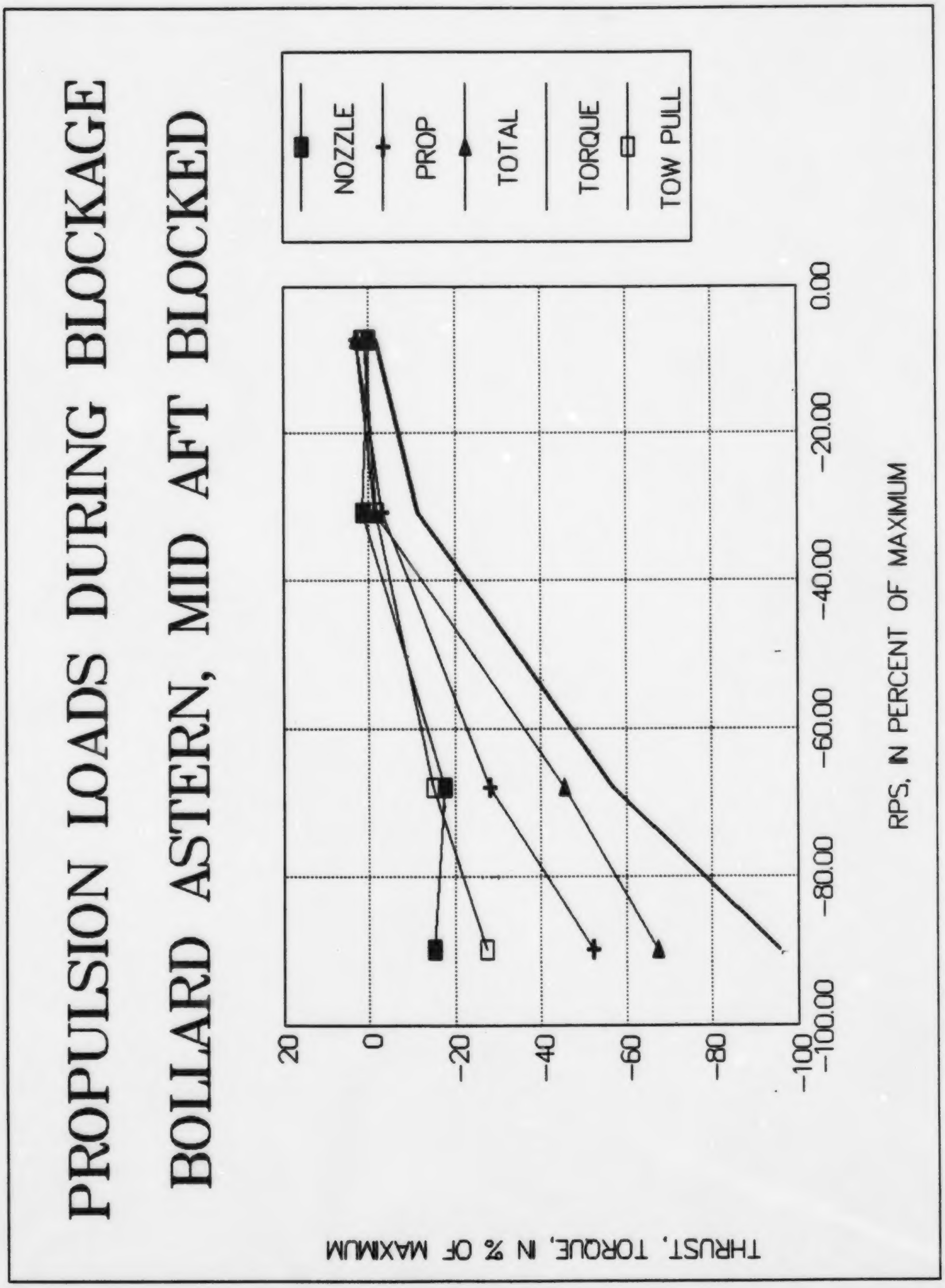


Figure 11.8



PROPULSION LOADS DURING BLOCKAGE
BOLLARD ASTERN, MID AFT BLOCKED

Figure 11.9

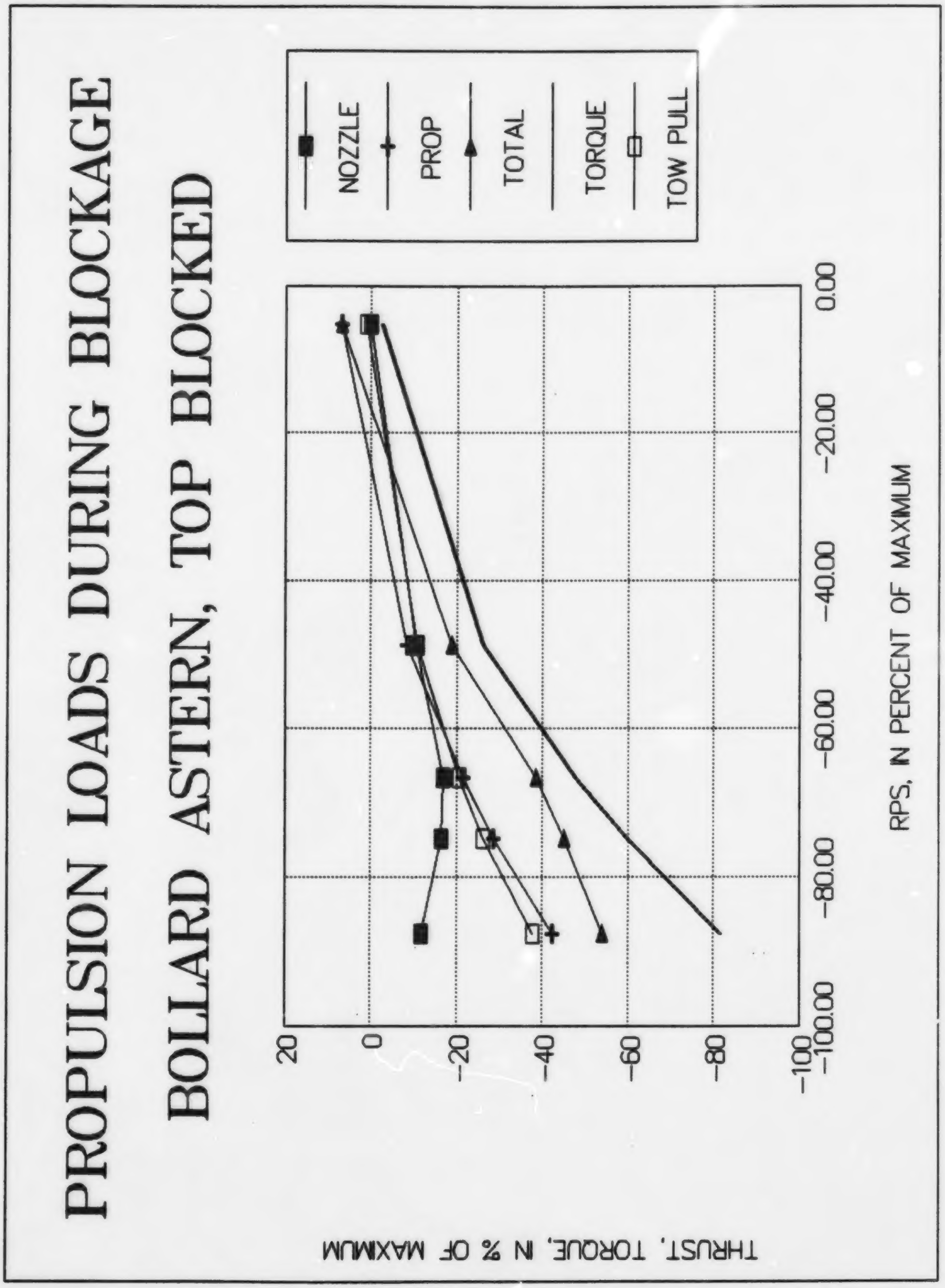

PROPULSION LOADS DURING BLOCKAGE
BOLLARD ASTERN, TOP BLOCKED
NOZZLE
PROP
TOTAL
TORQUE
TOW PULL
THRUST, TORQUE, IN % OF MAXIMUM
20
0
-20
-40
-60
-80
-100
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
RPS, IN PERCENT OF MAXIMUM

Figure 11.10

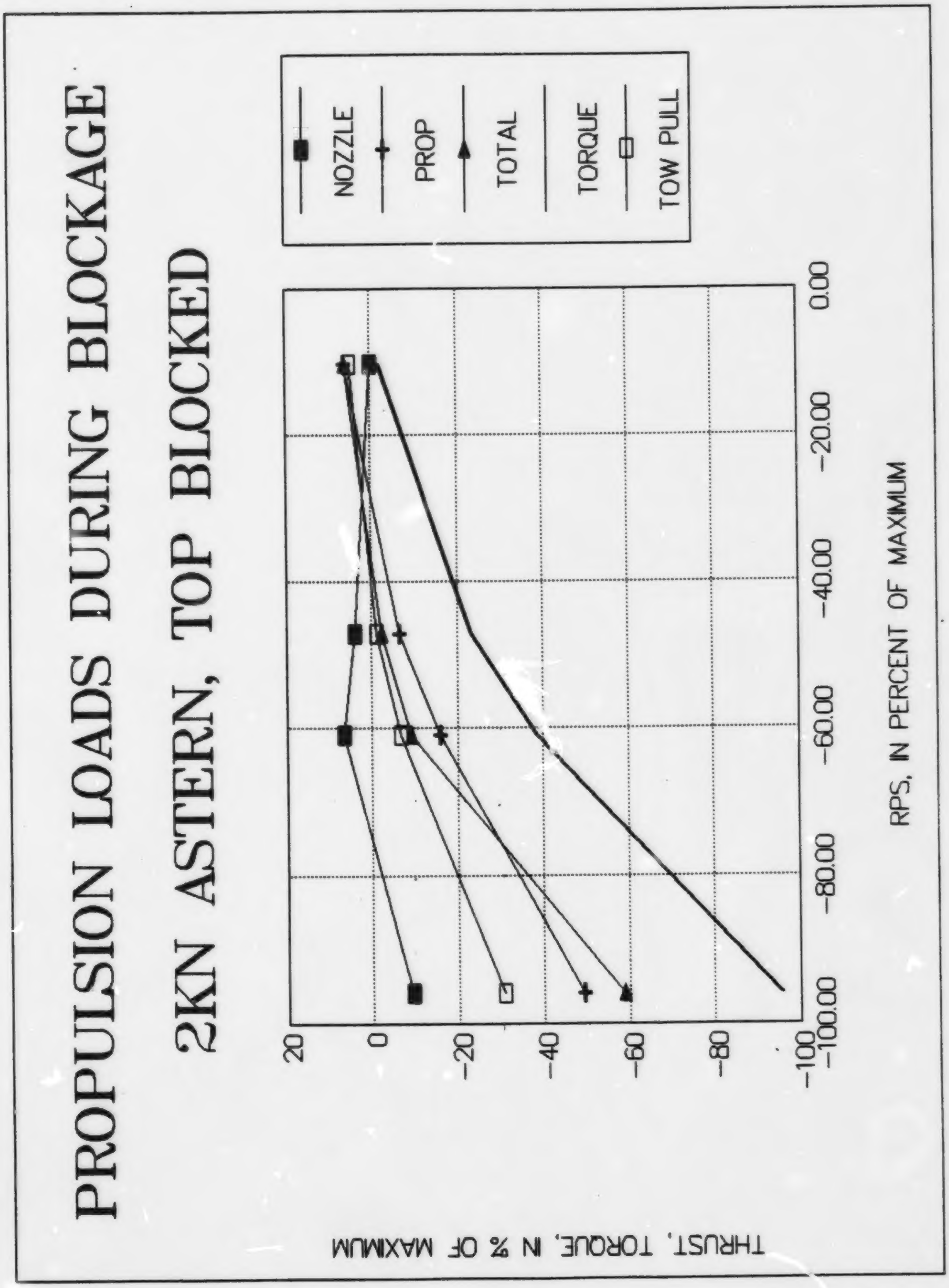
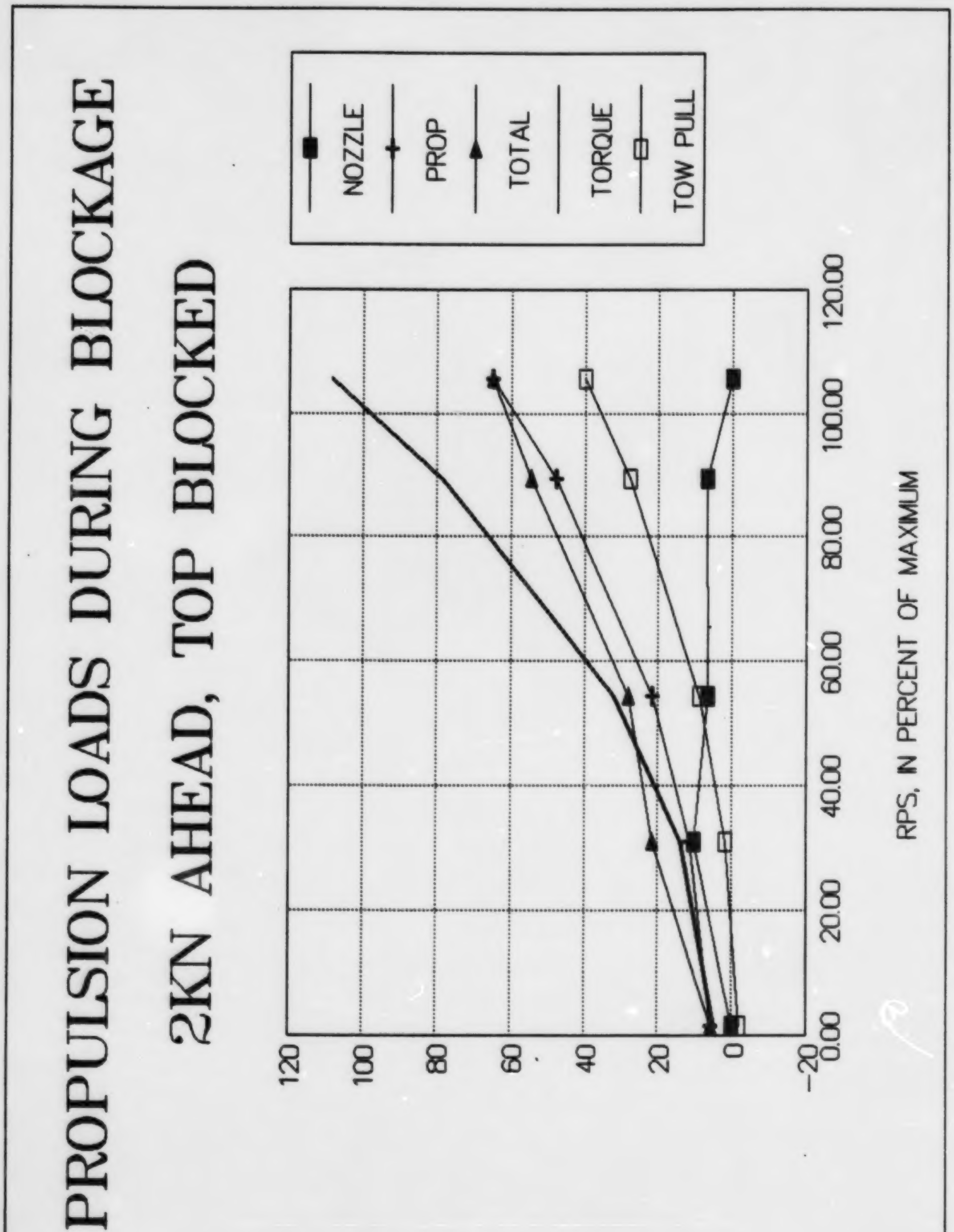
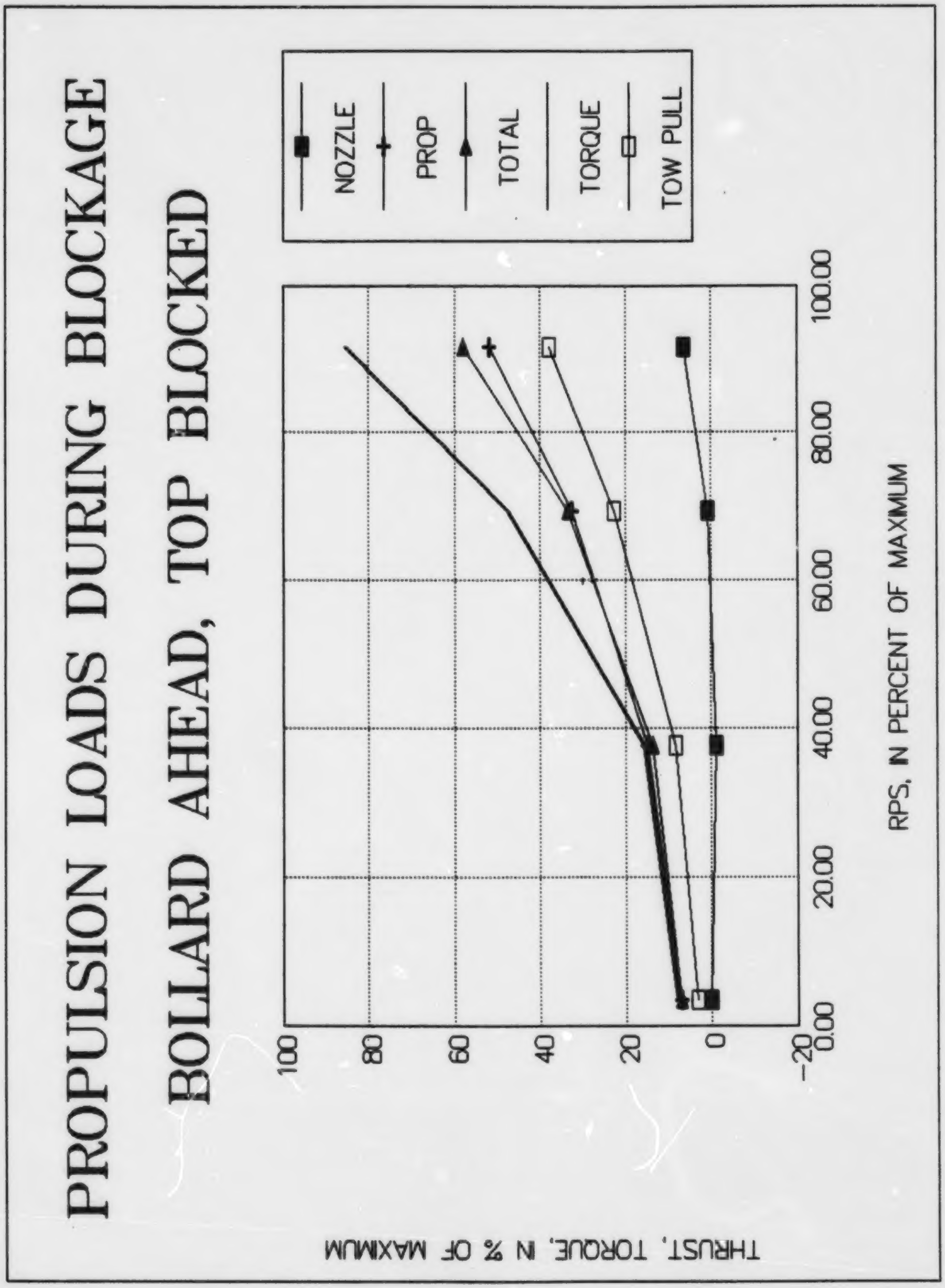

PROPULSION LOADS DURING BLOCKAGE
2KN ASTERN, TOP BLOCKED
NOZZLE
PROP
TOTAL
TORQUE
TOW PULL
THRUST, TORQUE, IN % OF MAXIMUM
20
0
-20
-40
-60
-80
-100
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
RPS, IN PERCENT OF MAXIMUM

Figure 11.11


PROPULSION LOADS DURING BLOCKAGE
2KN AHEAD, TOP BLOCKED
NOZZLE
PROP
TOTAL
TORQUE
TOW PULL
THRUST, TORQUE, IN % OF MAXIMUM
120
100
80
60
40
20
0
-20
0.00
20.00
40.00
60.00
80.00
100.00
120.00
RPS, IN PERCENT OF MAXIMUM

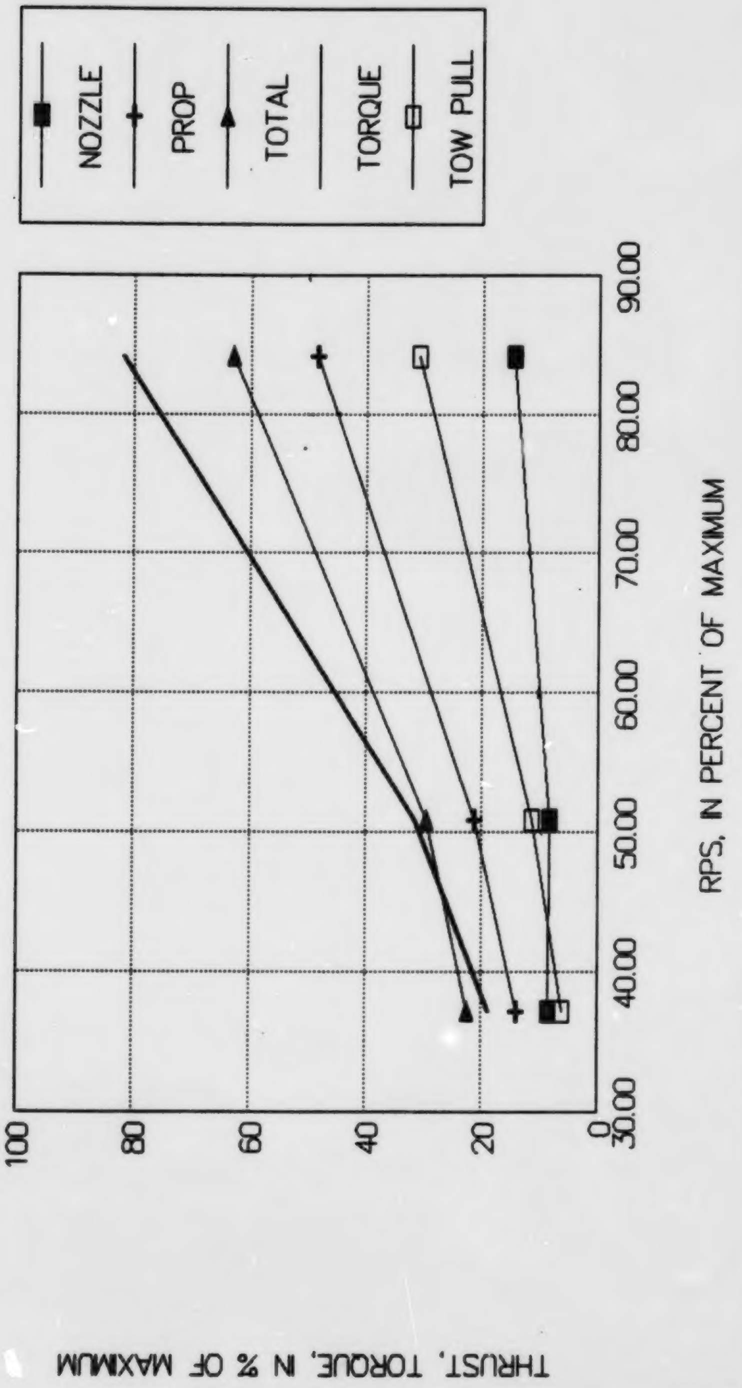


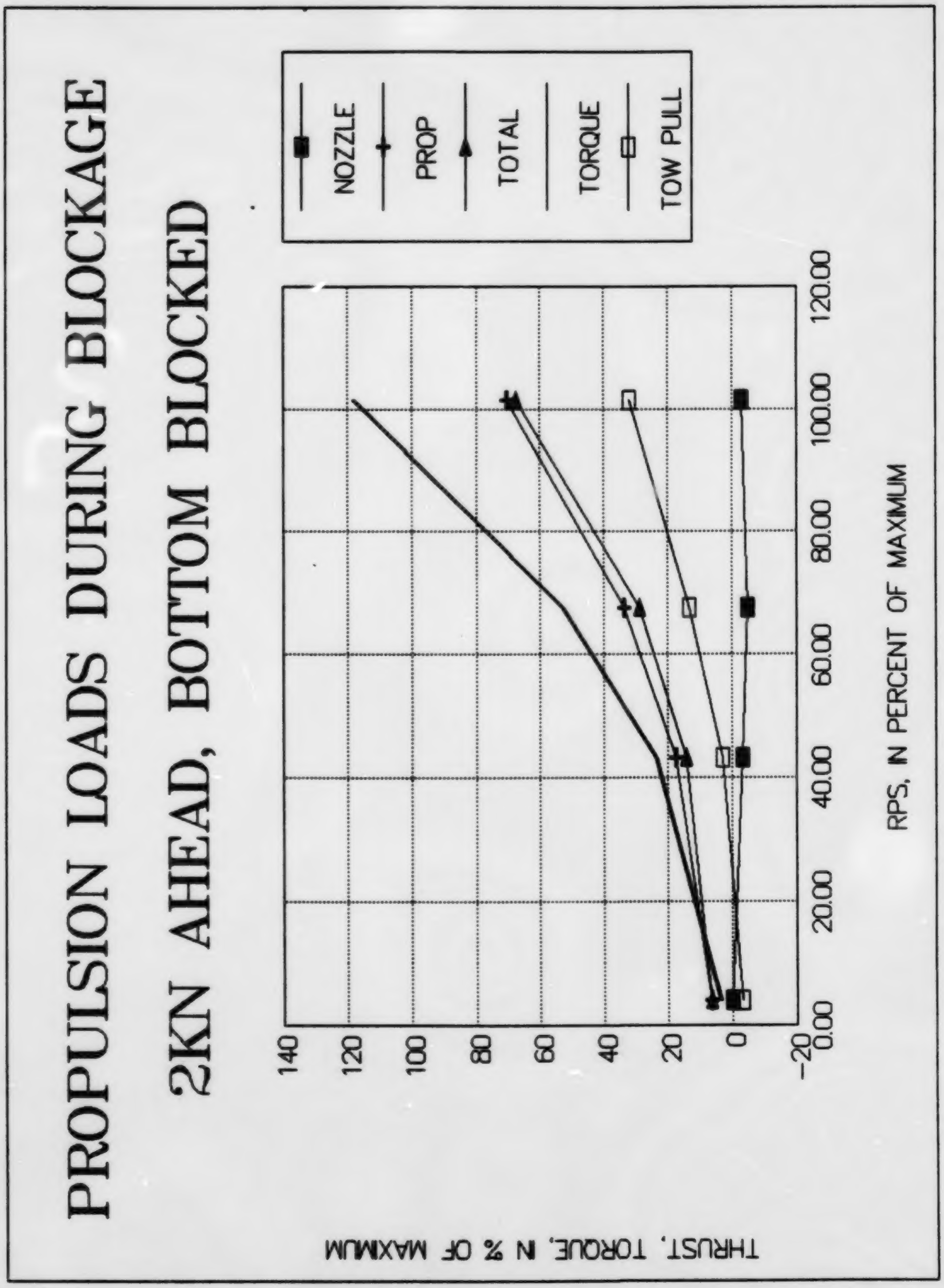
PROPULSION LOADS DURING BLOCKAGE

BOLLARD AHEAD, TOP BLOCKED

Figure 11.13

# PROPULSION LOADS DURING BLOCKAGE
# BOLLARD AHEAD, BOTTOM BLOCKED





PROPULSION LOADS DURING BLOCKAGE

2KN AHEAD, BOTTOM BLOCKED

## PROPULSION LOADS DURING BLOCKAGE
## BOLLARD ASTERN, BOTTOM BLOCKED

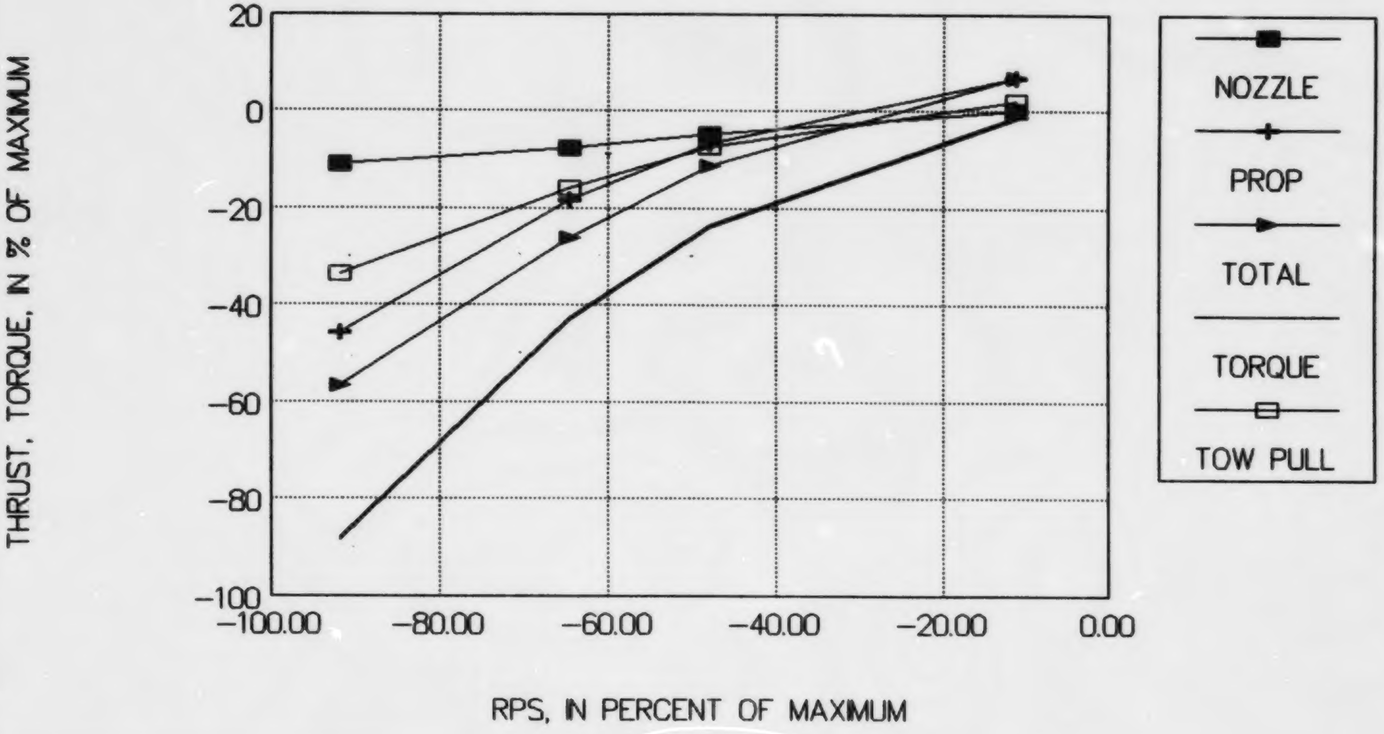
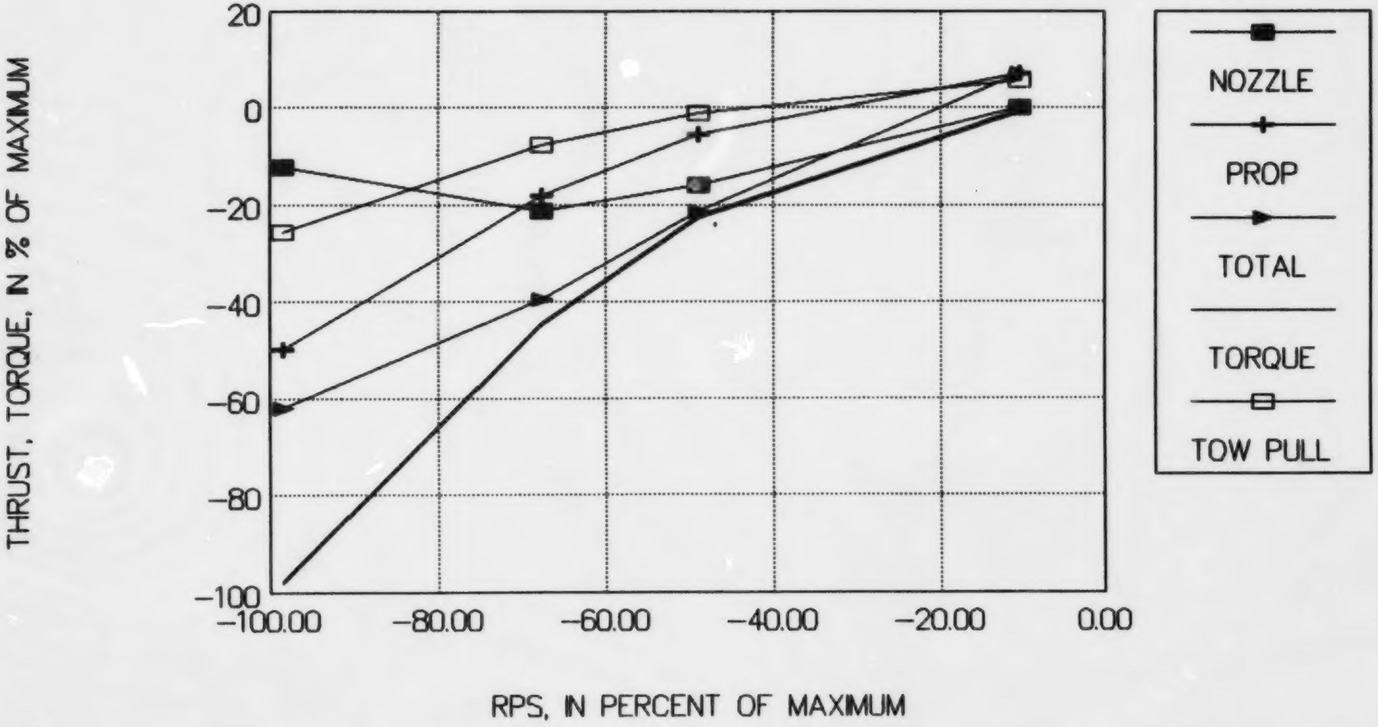


Figure 11.16



PROPULSION LOADS DURING BLOCKAGE

2KN ASTERN, BOTTOM BLOCKED

Figure 11.17

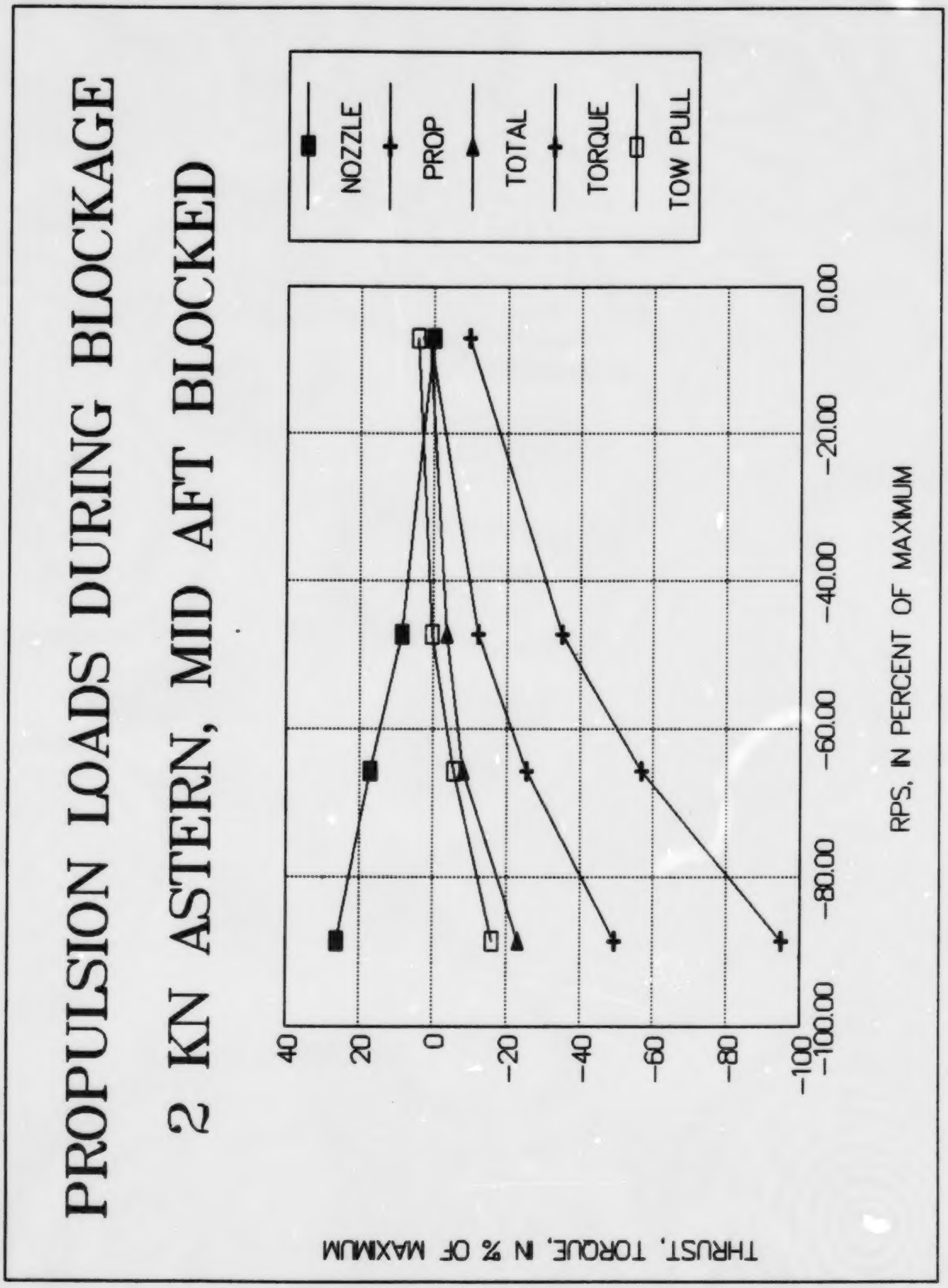
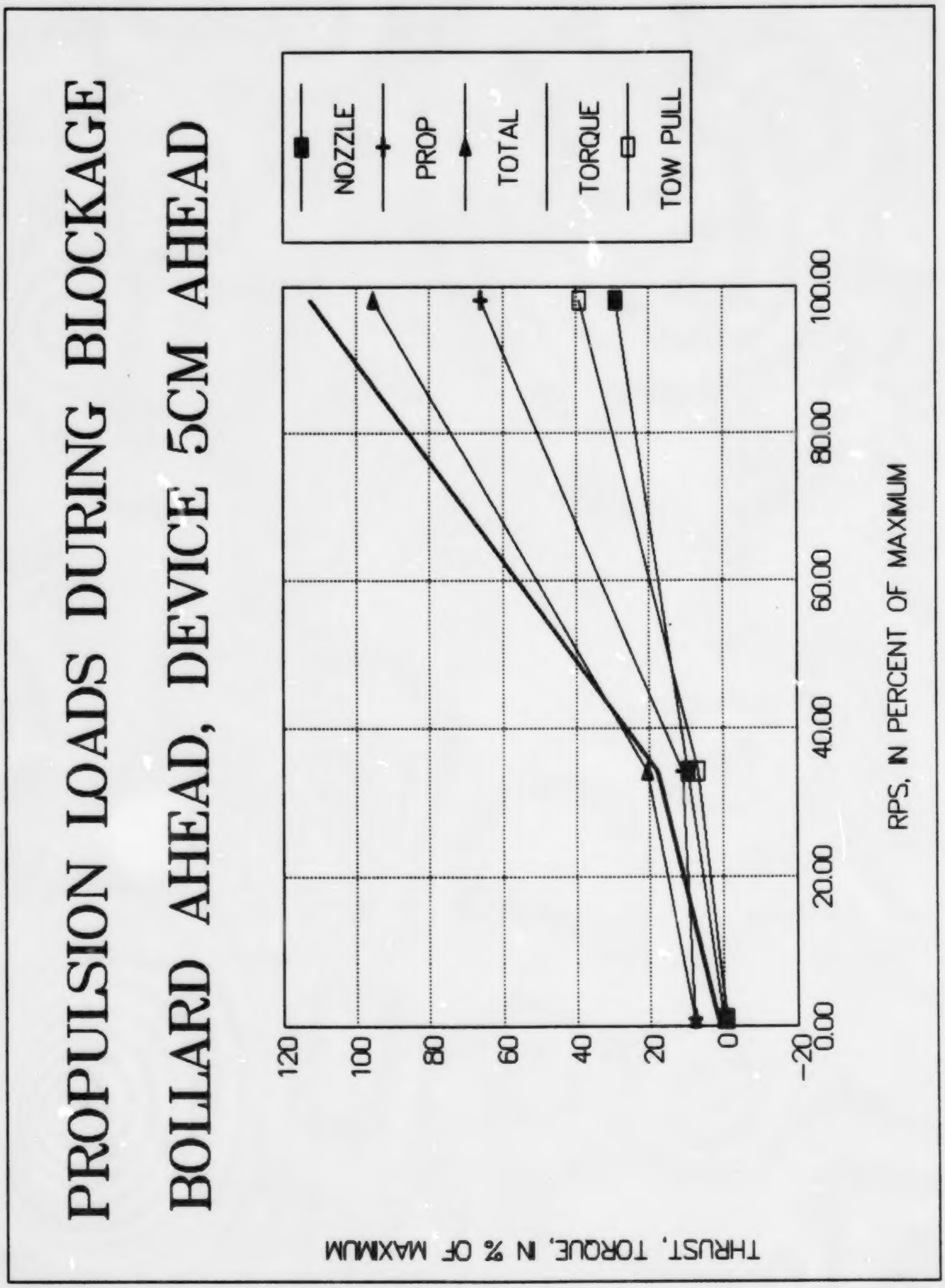
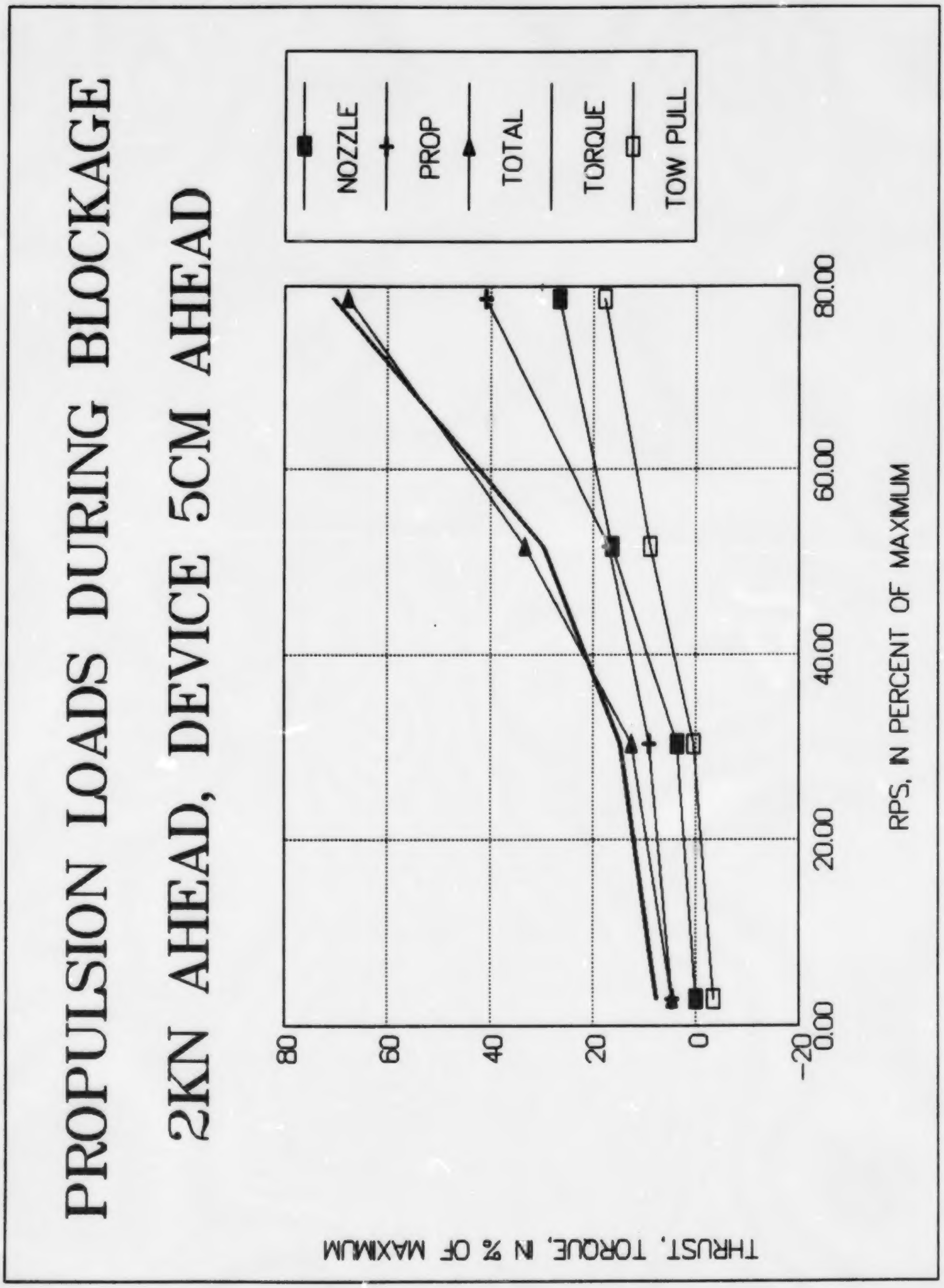

PROPULSION LOADS DURING BLOCKAGE
2 KN ASTERN, MID AFT BLOCKED
NOZZLE
PROP
TOTAL
TORQUE
TOW PULL
THRUST, TORQUE, IN % OF MAXIMUM
40
20
0
-20
-40
-60
-80
-100
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
RPS, IN PERCENT OF MAXMUM

Figure 11.18



PROPULSION LOADS DURING BLOCKAGE BOLLARD AHEAD, DEVICE 5CM AHEAD

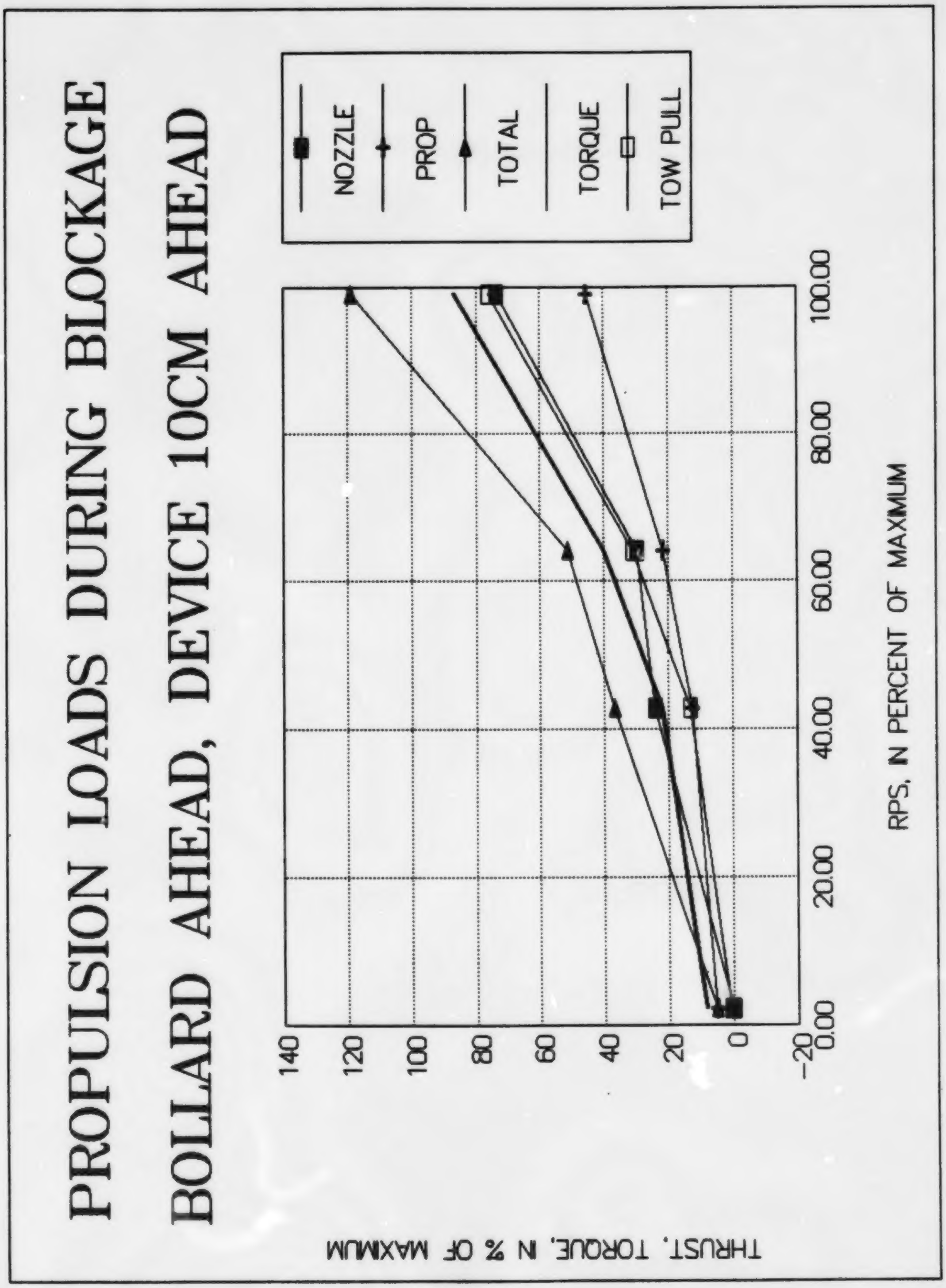
Figure 11.19



PROPULSION LOADS DURING BLOCKAGE

2KN AHEAD, DEVICE 5CM AHEAD

Figure 11.20



PROPULSION LOADS DURING BLOCKAGE BOLLARD AHEAD, DEVICE 10CM AHEAD

Figure 11.21

## PROPULSION LOADS DURING BLOCKAGE
## 2KN AHEAD, DEVICE 10CM AHEAD

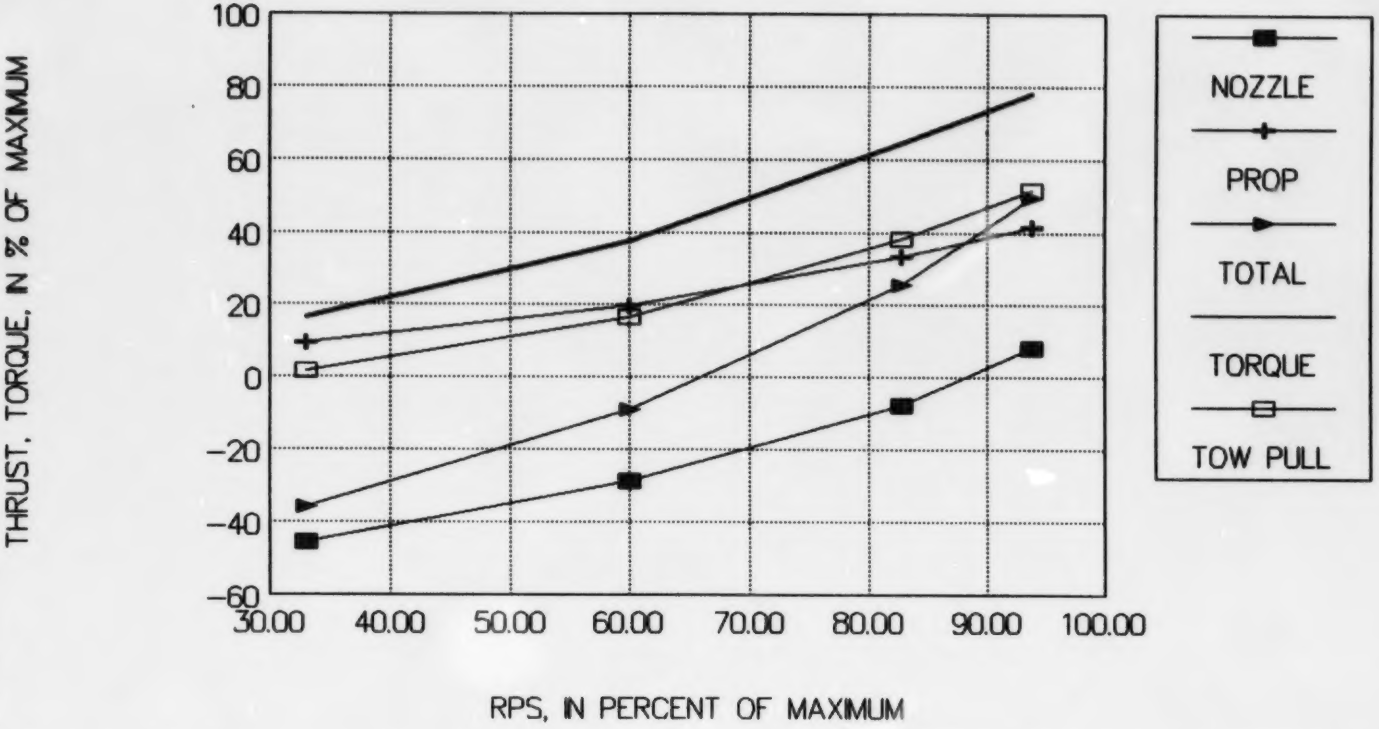


TABLE 11.3a

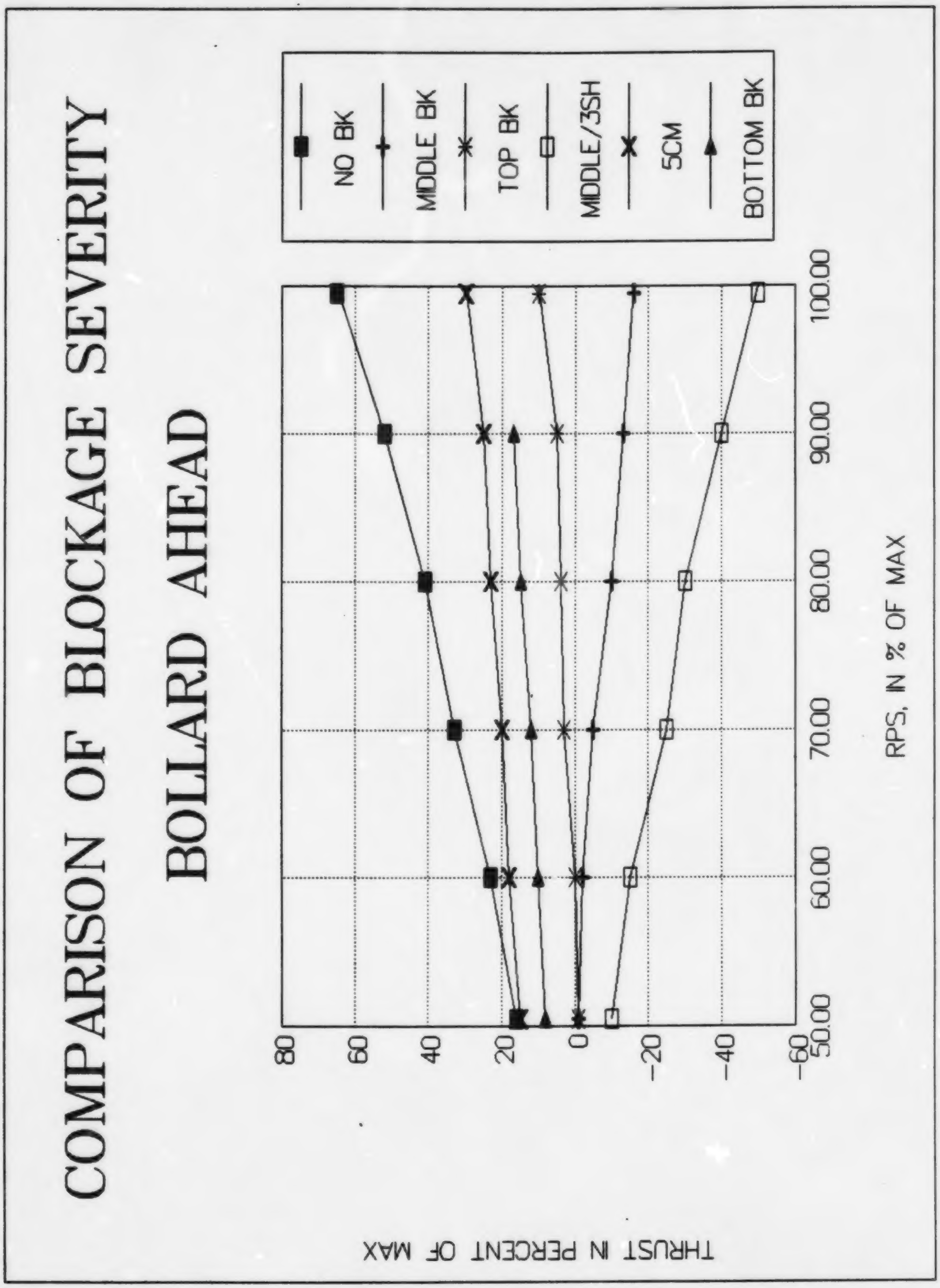
SUMMARY OF BLOCKAGE DATA, AHEAD CONDITION

| RPS IN % OF 8 | NOZZLE | PROP | TOTAL | TORQUE IN %OF 7.84 Nm | TOW PULL % OF 232.5N | POWER IN % OF 394W | TOW PULL / POWER | THRUST | NOZZLE | PROP | TOTAL | TORQUE IN % OF 7.84Nm | TOW PULL % OF 232.5N | POWER IN % OF 394W | TOW PULL / POWER | THRUST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | THRUST % OF 232.5 N | | | | | | % OF NOMINAL | | THRUST % OF 232.5 | | | | | | % OF NOMINAL | |
| | BOLLARD AHEAD, NO BLOCKAGE, ALL 3 SHAFTS | | | | | | | | 5 KNOTS AHEAD, NO BLOCKAGE, ALL 3 SHAFTS | | | | | | | |
| 50 | 16 | 17 | 33 | 25 | 60 | 12.5 | 480 | 1.8 | 7 | 13 | 20 | 23 | | 11.5 | | |
| 60 | 23 | 20 | 43 | 34 | 83 | 20.4 | 407 | 1.9 | 12 | 16 | 28 | 29 | | 17.4 | | |
| 70 | 33 | 25 | 58 | 44 | 130 | 30.8 | 422 | 2.2 | 18 | 22 | 40 | 40 | | 28.0 | | |
| 80 | 41 | 31 | 72 | 54 | 193 | 43.2 | 447 | 2.7 | 26 | 27 | 53 | 51 | | 40.8 | | |
| 90 | 52 | 38 | 90 | 75 | 205 | 67.5 | 304 | 2.3 | 34 | 38 | 72 | 65 | | 58.5 | | |
| 100 | 65 | 48 | 113 | 100 | | 100.0 | | | 43 | 50 | 93 | 85 | | 85.0 | | |
| | 10 KNOTS AHEAD,NO BLOCKAGE, ALL 3 SHAFTS | | | | | | | | 15 KNOTS AHEAD, NO BLOCKAGE, ALL 3 SHAFTS | | | | | | | |
| 50 | 4 | 8 | 12 | 16 | | | | | -8 | 11 | 3 | -6 | | -3.0 | | |
| 60 | 7 | 10 | 17 | 23 | | | | | -3 | 10 | 7 | 12 | | 7.2 | | |
| 70 | 12 | 15 | 27 | 28 | | | | | 2 | 10 | 12 | 26 | | 18.2 | | |
| 80 | 16 | 22 | 38 | 40 | | | | | 5 | 10 | 15 | 38 | | 30.4 | | |
| 90 | 22 | 28 | 50 | 53 | | | | | 10 | 10 | 20 | 55 | | 49.5 | | |
| 100 | 28 | 33 | 61 | | | | | | 13 | 10 | 23 | | | 0.0 | | |
| | BLOCKAGE MID FORE | | | | | | | | | | | | | | | |
| | BOLLARD AHEAD, ALL 3 SHAFTS | | | | | | | | BOLLARD AHEAD, CENTER ONLY | | | | | | | |
| 50 | -10 | 18 | 8 | 38 | 38 | 19.0 | 200 | 4.8 | -1 | 15 | 14 | 28 | 7 | 14.0 | 50 | 0.5 |
| 60 | -15 | 25 | 10 | 47 | 47 | 28.2 | 167 | 4.7 | -2 | 21 | 19 | 38 | 10 | 22.8 | 44 | 0.5 |
| 70 | -25 | 35 | 10 | 60 | 80 | 42.0 | 190 | 8.0 | -5 | 27 | 22 | 55 | 12 | 38.5 | 31 | 0.5 |
| 80 | -30 | 45 | 15 | 75 | 110 | 60.0 | 183 | 7.3 | -9 | 38 | 29 | 75 | 17 | 60.0 | 28 | 0.6 |
| 90 | -40 | 53 | 13 | 98 | 140 | 88.2 | 159 | 10.8 | -13 | 48 | 35 | 95 | 21 | 85.5 | 25 | 0.6 |
| 100 | -50 | 60 | 10 | 115 | | 115.0 | 0 | | -16 | 58 | 42 | | 25 | | | 0.6 |
| | 5 KNOTS AHEAD, CENTER ONLY | | | | | | | | 15 KNOTS AHEAD, CENTER ONLY | | | | | | | |
| 50 | -5 | 10 | 5 | 30 | -18 | 15.0 | -120 | -3.6 | -38 | -10 | -48 | 3 | -212 | 1.5 | -14133 | 4.4 |
| 60 | -7 | 18 | 11 | 41 | -18 | 24.6 | -73 | -1.6 | -41 | 0 | -41 | 18 | -209 | 10.8 | -1935 | 5.1 |
| 70 | -8 | 26 | 18 | 55 | -15 | 38.5 | -39 | -0.8 | -44 | 10 | -34 | 25 | -206 | 17.5 | -1177 | 6.1 |
| 80 | -12 | 35 | 23 | 70 | -10 | 56.0 | -18 | -0.4 | -50 | 21 | -29 | 47 | -203 | 37.6 | -540 | 7.0 |
| 90 | -18 | 45 | 27 | 90 | -5 | 81.0 | -6 | -0.2 | -52 | 27 | -25 | 68 | -200 | 61.2 | -327 | 8.0 |
| 100 | -26 | 58 | 32 | | -2 | | | -0.1 | -60 | 40 | -20 | 75 | -194 | 75.0 | -259 | 9.7 |
| | BLOCKAGE TOP FORE | | | | | | | | BLOCKAGE BOTTOM FORE | | | | | | | |
| | BOLLARD AHEAD, CENTER ONLY | | | | | | | | BOLLARD AHEAD, CENTER ONLY | | | | | | | |
| 50 | -1 | 23 | 22 | 28 | 15 | 14.0 | 107 | 0.7 | 8 | 22 | 30 | 32 | 12 | 16.0 | 75 | 0.4 |
| 60 | 0 | 27 | 27 | 37 | 18 | 22.2 | 81 | 0.7 | 10 | 27 | 37 | 45 | 16 | 27.0 | 59 | 0.4 |
| 70 | 3 | 33 | 36 | 52 | 23 | 36.4 | 63 | 0.6 | 12 | 37 | 49 | 60 | 22 | 42.0 | 52 | 0.4 |
| 80 | 4 | 42 | 46 | 68 | 30 | 54.4 | 55 | 0.7 | 15 | 45 | 60 | 75 | 28 | 60.0 | 47 | 0.5 |
| 90 | 6 | 52 | 58 | 85 | 38 | 76.5 | 50 | 0.7 | 17 | 54 | 71 | 90 | 35 | 81.0 | 43 | 0.5 |
| 100 | 10 | 60 | 70 | 100 | 43 | 100.0 | 43 | 0.6 | | | | | | | | |
| | BOLLARD AHEAD, CENTER ONLY, 5CM DISTANCE | | | | | | | | BOLLARD AHEAD, CENTER ONLY, 10CM DISTANCE | | | | | | | |
| 50 | 15 | 25 | 40 | 42 | 15 | 21.0 | 71 | 0.4 | 26 | 16 | 42 | 29 | 20 | 14.5 | 138 | 0.5 |
| 60 | 18 | 33 | 51 | 58 | 20 | 34.8 | 57 | 0.4 | 29 | 20 | 49 | 37 | 28 | 22.2 | 126 | 0.6 |
| 70 | 20 | 42 | 62 | 70 | 25 | 49.0 | 51 | 0.4 | 38 | 26 | 64 | 50 | 39 | 35.0 | 111 | 0.6 |
| 80 | 23 | 50 | 73 | 85 | 30 | 68.0 | 44 | 0.4 | 50 | 32 | 82 | 62 | 51 | 49.6 | 103 | 0.6 |
| 90 | 25 | 60 | 85 | 100 | 35 | 90.0 | 39 | 0.4 | 63 | 40 | 103 | 75 | 65 | 67.5 | 96 | 0.6 |
| 100 | 30 | 68 | 98 | 115 | 40 | 115.0 | 35 | 0.4 | 75 | 45 | 120 | 85 | 78 | 85.0 | 92 | 0.7 |
| | 2 KN AHEAD, CENTER ONLY, 5CM DISTANCE | | | | | | | | 2 KN AHEAD, CENTER ONLY, 10CM DISTANCE | | | | | | | |
| 50 | 15 | 18 | 33 | 30 | 8 | 15.0 | 53 | 0.2 | -35 | 16 | -17 | 30 | 10 | 15.0 | 67 | -0.6 |
| 60 | 19.5 | 24.5 | 44 | 42 | 10 | 25.2 | 40 | 0.2 | -30 | 20 | -10 | 37 | 18 | 22.2 | 81 | -1.8 |
| 70 | 23 | 35 | 58 | 60 | 15 | 42.0 | 36 | 0.3 | -20 | 25 | 5 | 50 | 25 | 35.0 | 71 | 5.0 |
| 80 | 27 | 43 | 70 | 73 | 18 | 58.4 | 31 | 0.3 | -10 | 32 | 22 | 61 | 35 | 48.8 | 72 | 1.6 |
| 90 | | | | | | | | | 3 | 38 | 41 | 74 | 47 | 66.6 | 71 | 1.1 |
| 100 | | | | | | | | | 16 | 45 | 61 | 85 | 60 | 85.0 | 71 | 1.0 |

TABLE 11.3b

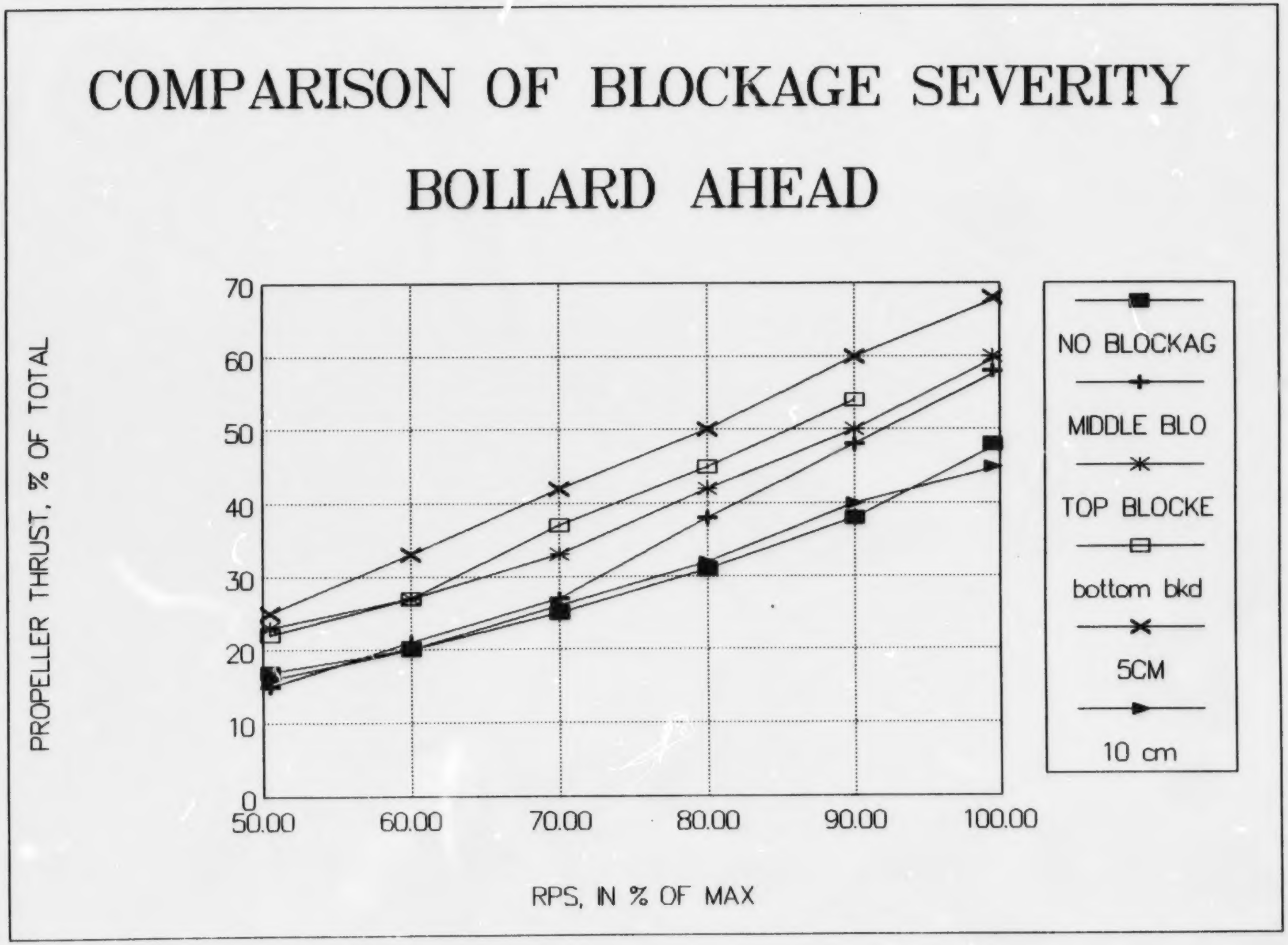
SUMMARY OF BLOCKAGE DATA, ASTERN CONDITION

| RPS IN % OF 8 | NOZZLE | PROP | TOTAL | TORQUE IN %OF 7.84 Nm | TOW PULL % OF 232.5N | POWER IN % OF 394W | TOW PULL / POWER | THRUST | NOZZLE | PROP | TOTAL | TORQUE IN % OF 7.84Nm | TOW PULL % OF 232.5N | POWER IN % OF 394W | TOW PULL / POWER | THRUST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | THRUST % OF 232.5 N | | | | | | % OF NOMINAL | | THRUST % OF 232.5 | | | | | | % OF NOMINAL | |
| | BOLLARD ASTERN, MIDLLE BLOCKED | | | | | | | | BOLLARD ASTERN, TOP BLOCKED | | | | | | | |
| 50 | -8 | -16 | -24 | -35 | -8 | -17.5 | 46 | 0.3 | -10 | -9 | -19 | -28 | -11 | -14.0 | 79 | 0.6 |
| 60 | -13 | -22 | -35 | -48 | -12 | -28.8 | 42 | 0.3 | -15 | -17 | -32 | -40 | -17 | -24.0 | 71 | 0.5 |
| 70 | -17 | -31 | -48 | -60 | -16 | -42.0 | 38 | 0.3 | -18 | -23 | -41 | -52 | -22 | -36.4 | 60 | 0.5 |
| 80 | -23 | -42 | -65 | -78 | -22 | -62.4 | 35 | 0.3 | -15 | -34 | -49 | -68 | -30 | -54.4 | 55 | 0.6 |
| 90 | -35 | -52 | -87 | -96 | -32 | -86.4 | 37 | 0.4 | -10 | -45 | -55 | -90 | -40 | -81.0 | 49 | 0.7 |
| 100 | | | | | | | | | | | | | | | | |
| | 2 KN ASTERN, MIDDLE BLOCKED | | | | | | | | 2 KNOTS ASTERN, TOP BLOCKED | | | | | | | |
| 50 | 10 | -14 | -4 | -38 | -1 | -19.0 | 5 | 0.3 | 5 | -8 | -3 | -26 | -2 | -13.0 | 15 | 0.7 |
| 60 | 15 | -22 | -7 | -50 | -4 | -30.0 | 13 | 0.6 | 7 | -17 | -10 | -37 | -6 | -22.2 | 27 | 0.6 |
| 70 | 19 | -32 | -13 | -65 | -8 | -45.5 | 18 | 0.6 | 3 | -24 | -21 | -53 | -13 | -37.1 | 35 | 0.6 |
| 80 | 23 | -40 | -17 | -80 | -12 | -64.0 | 19 | 0.7 | -2 | -23 | -25 | -70 | -20 | -56.0 | 36 | 0.8 |
| 90 | 28 | -50 | -22 | -100 | -18 | -90.0 | 20 | 0.8 | -8 | -43 | -51 | -86 | -26 | -77.4 | 34 | 0.5 |
| 100 | | | | | | | | | -12 | -52 | -64 | -105 | -33 | -105.0 | 31 | 0.5 |
| | BOLLARD ASTERN, BOTTOM BLOCKED | | | | | | | | 2 KNOTS ASTERN, BOTTOM BLOCKED | | | | | | | |
| 50 | -5 | -8 | -13 | -26 | -8 | -13.0 | 62 | 0.6 | -16 | -7 | -23 | -24 | -2 | -12.0 | 17 | 0.1 |
| 60 | -7 | -15 | -22 | -37 | -13 | -22.2 | 59 | 0.6 | -19 | -13 | -32 | -36 | -5 | -21.6 | 23 | 0.2 |
| 70 | -8 | -24 | -32 | -52 | -20 | -36.4 | 55 | 0.6 | -20 | -21 | -41 | -49 | -9 | -34.3 | 26 | 0.2 |
| 80 | -9 | -34 | -43 | -68 | -26 | -54.4 | 48 | 0.6 | -18 | -30 | -48 | -65 | -15 | -52.0 | 29 | 0.3 |
| 90 | -11 | -43 | -54 | -86 | -32 | -77.4 | 41 | 0.6 | -15 | -41 | -56 | -82 | -21 | -73.8 | 28 | 0.4 |
| 100 | | | | | | | | | -12 | -50 | -62 | -100 | -25 | -100.0 | 25 | 0.4 |


COMPARISON OF BLOCKAGE SEVERITY

BOLLARD AHEAD

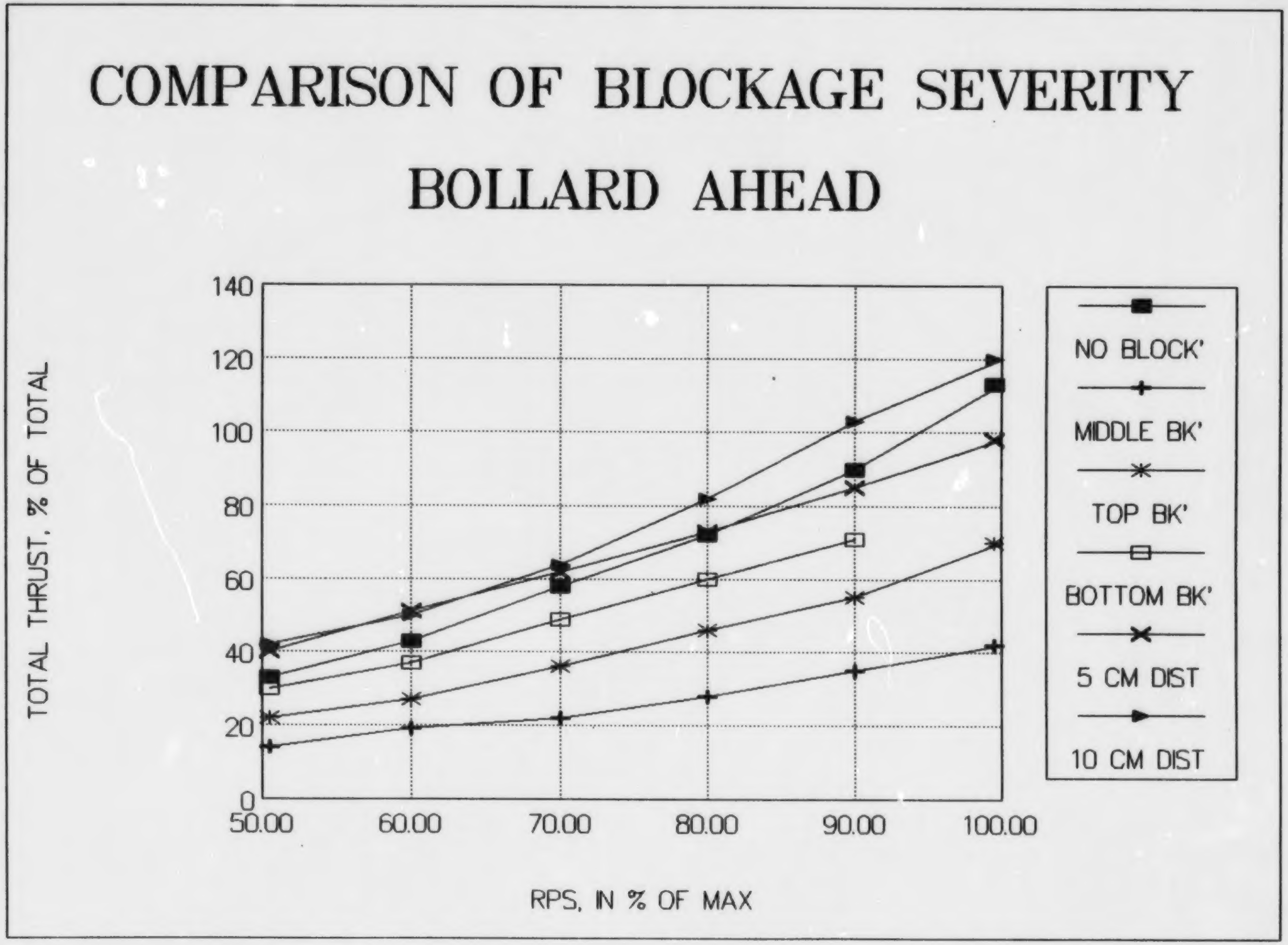
Figure 11.23

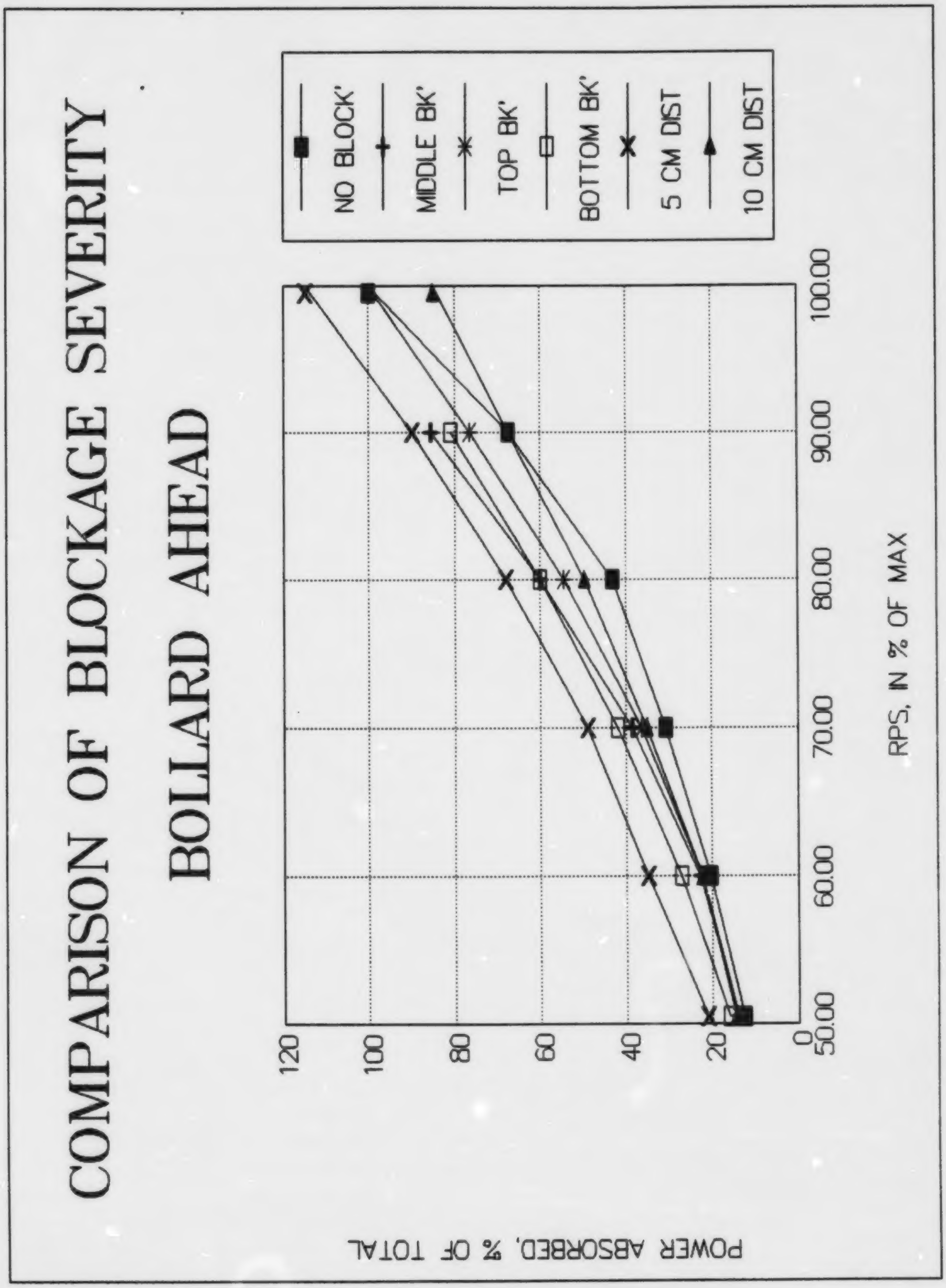


COMPARISON OF BLOCKAGE SEVERITY

BOLLARD AHEAD

Figure 11.24


COMPARISON OF BLOCKAGE SEVERITY
BOLLARD AHEAD
TOTAL THRUST, % OF TOTAL
0
20
40
60
80
100
120
140
50.00
60.00
70.00
80.00
90.00
100.00
RPS, IN % OF MAX
NO BLOCK'
MIDDLE BK'
TOP BK'
BOTTOM BK'
5 CM DIST
10 CM DIST



COMPARISON OF BLOCKAGE SEVERITY

BOLLARD AHEAD

Figure 11.26

COMPARISON OF BLOCKAGE SEVERITY

BOLLARD AHEAD

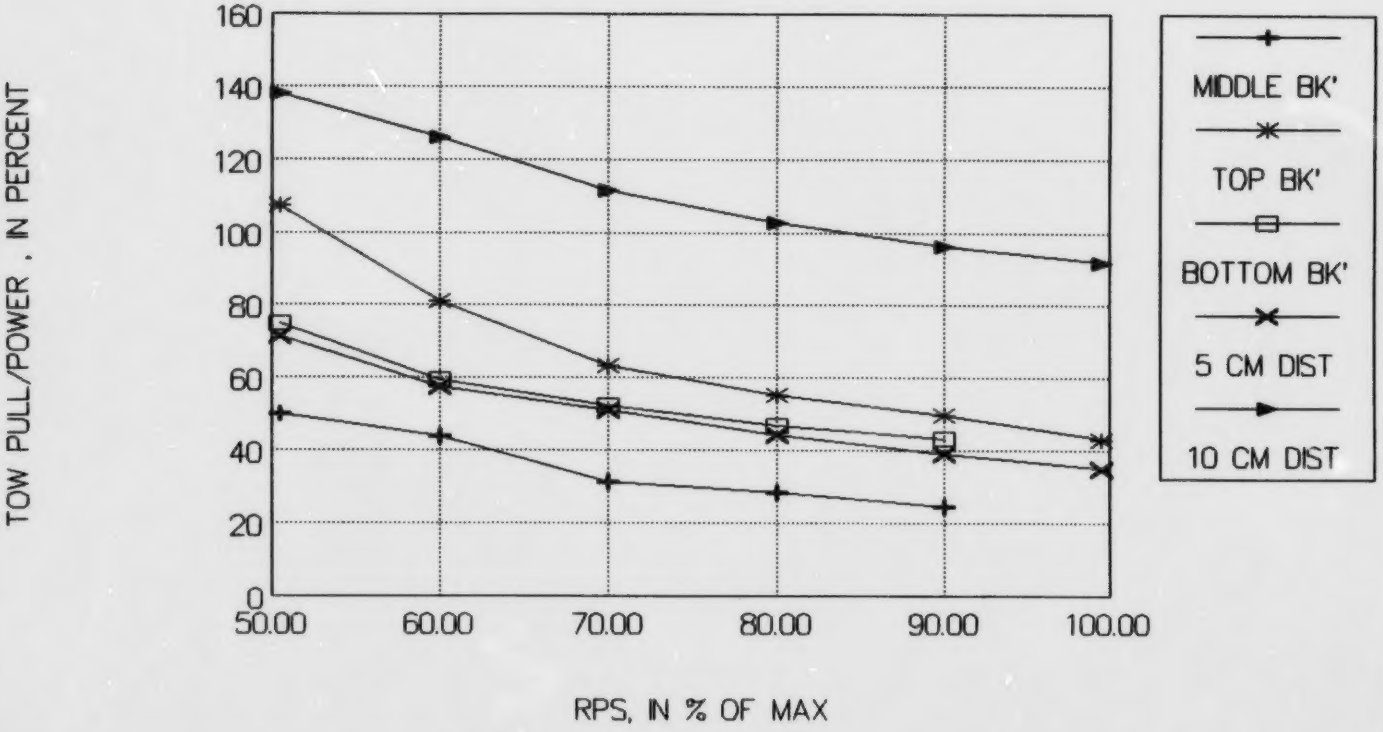
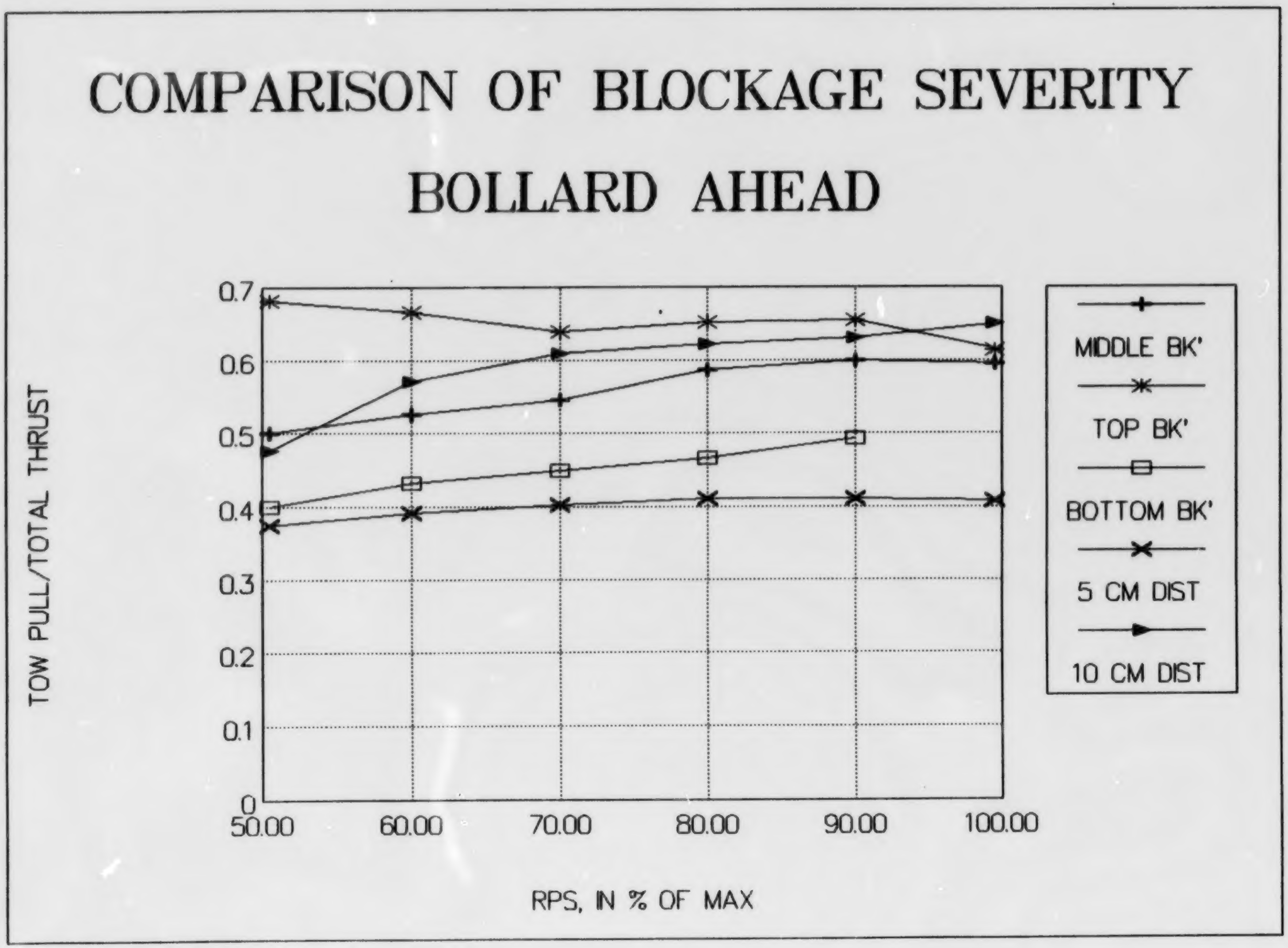


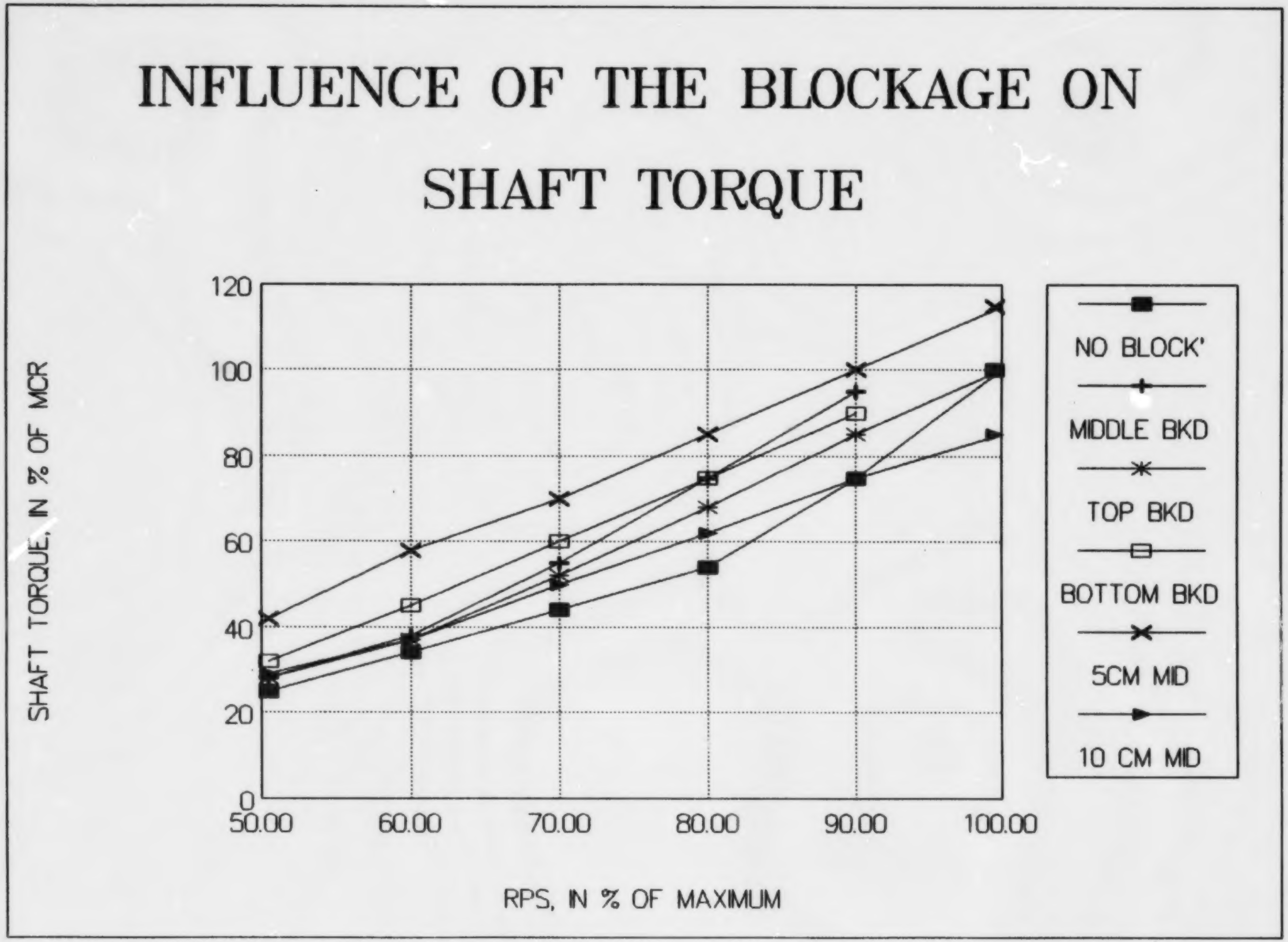
Figure 11.27



COMPARISON OF BLOCKAGE SEVERITY

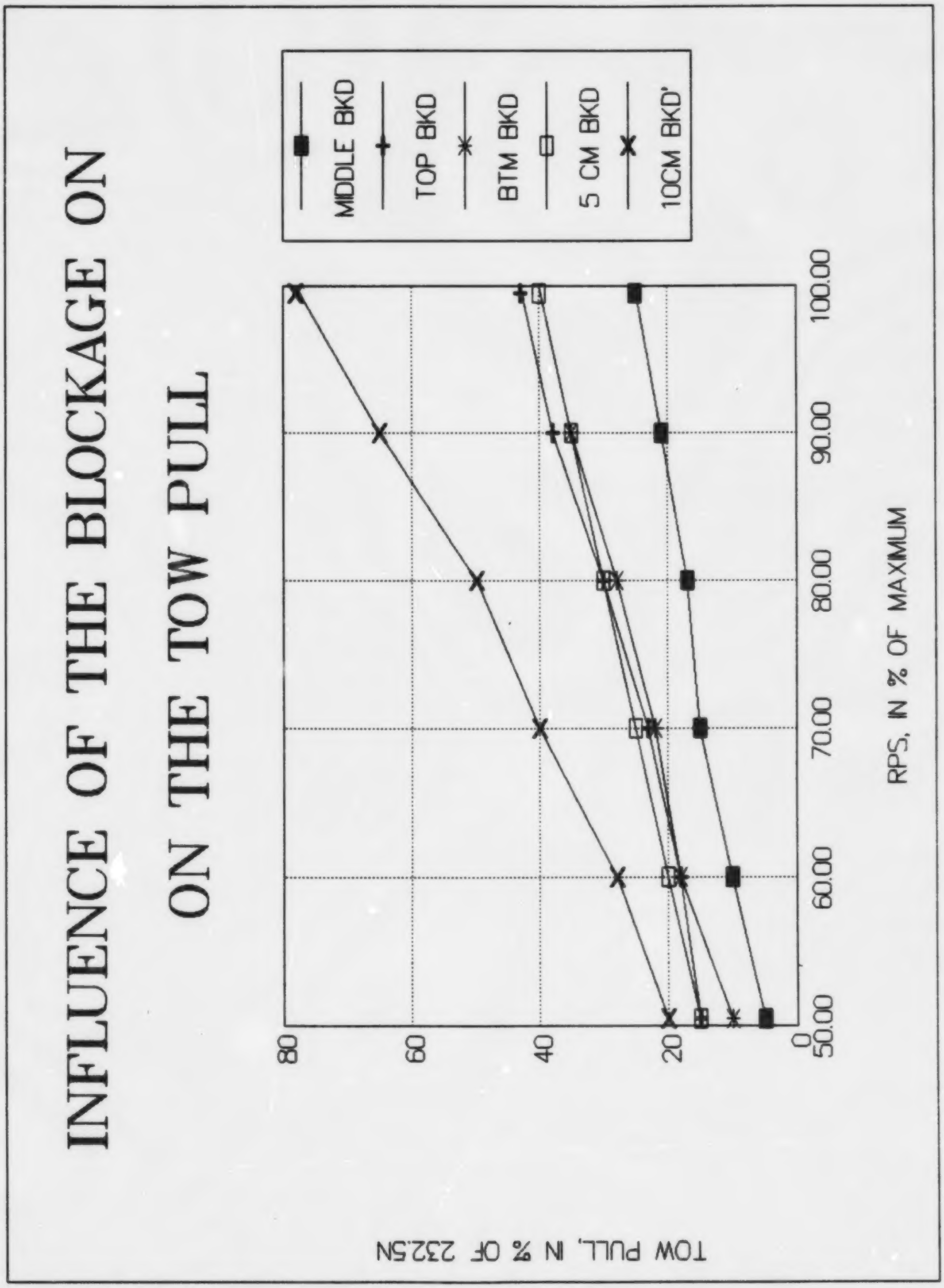
BOLLARD AHEAD

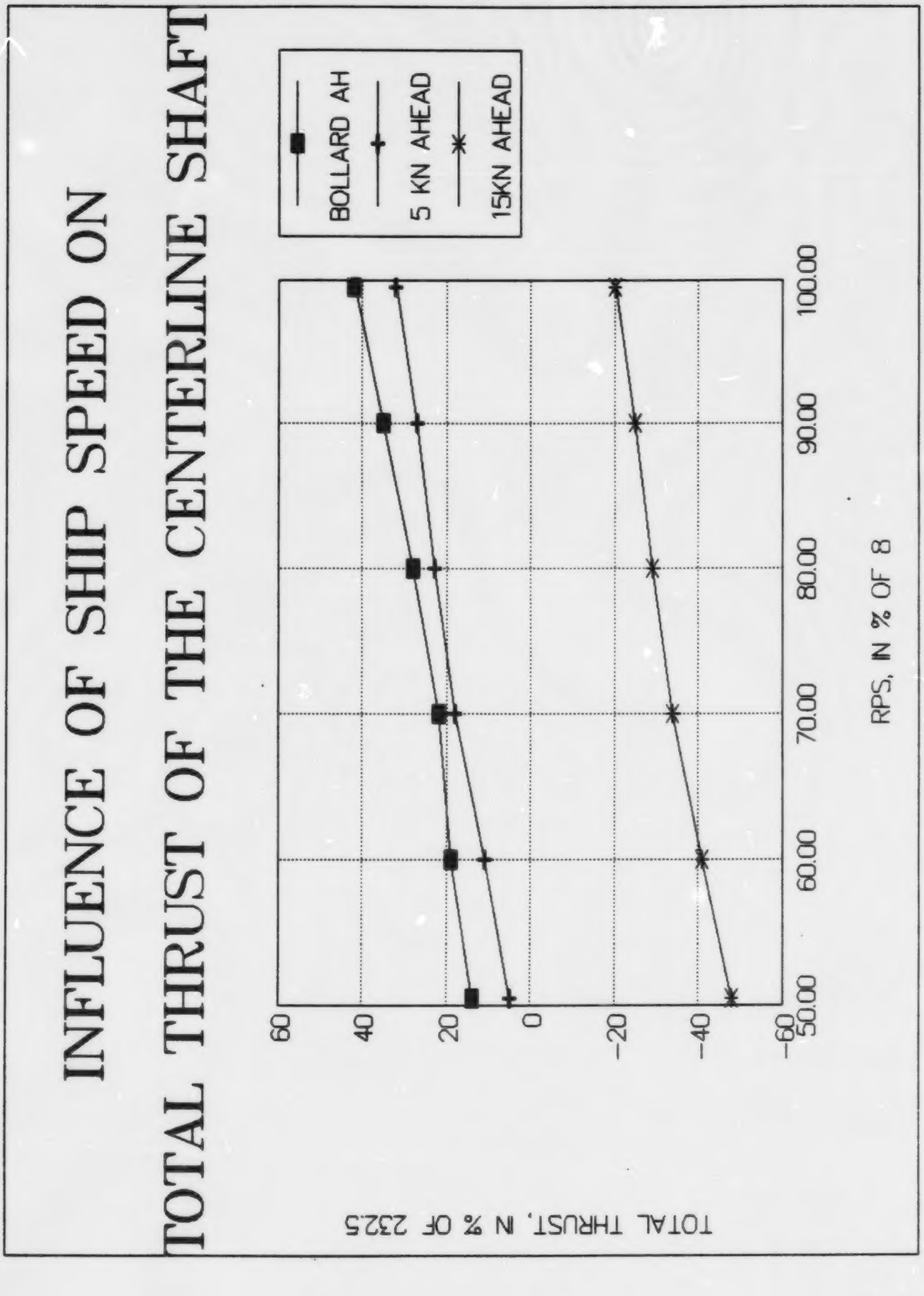
Figure 11.28



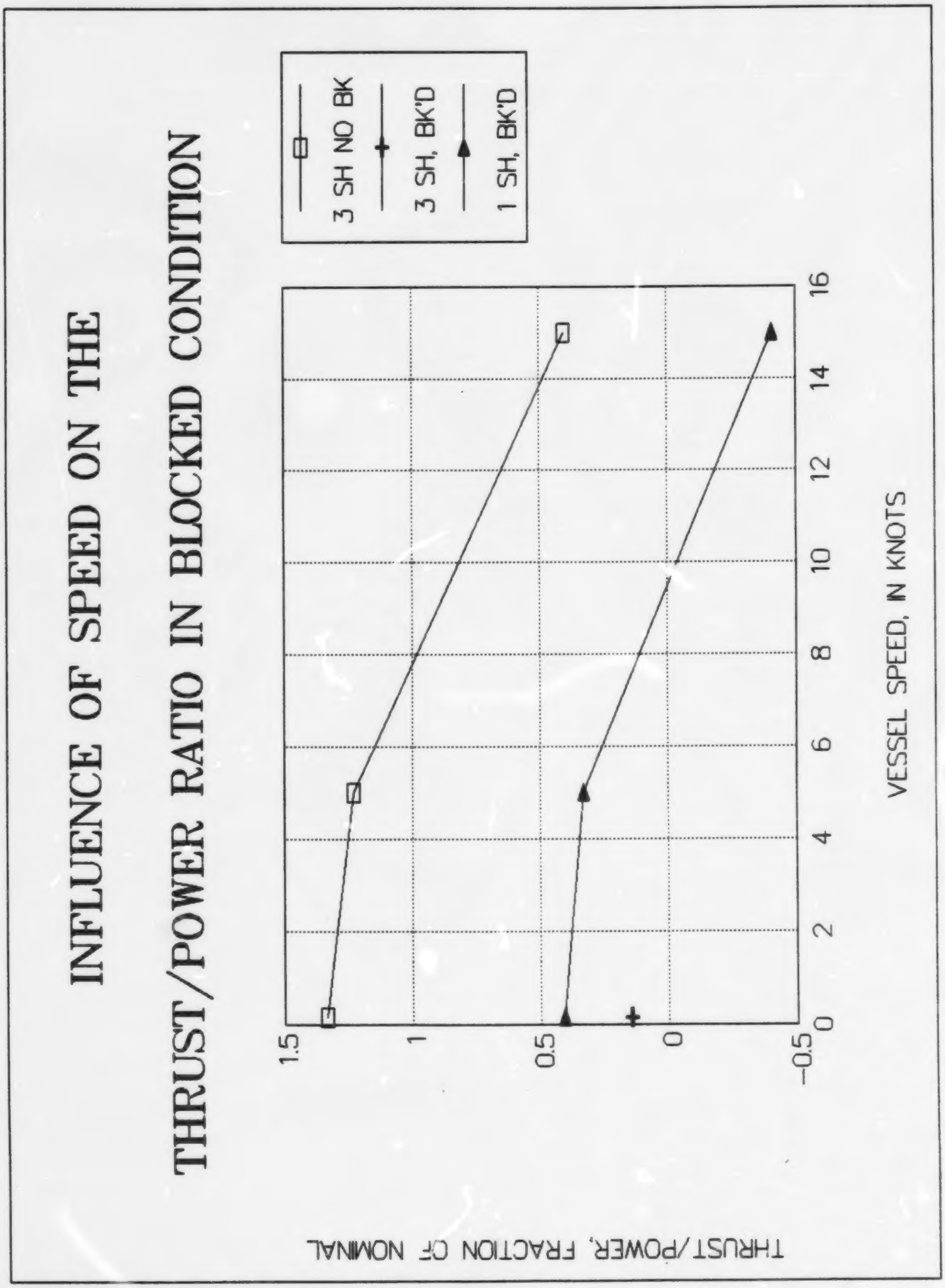
INFLUENCE OF THE BLOCKAGE ON SHAFT TORQUE

Figure 11.29

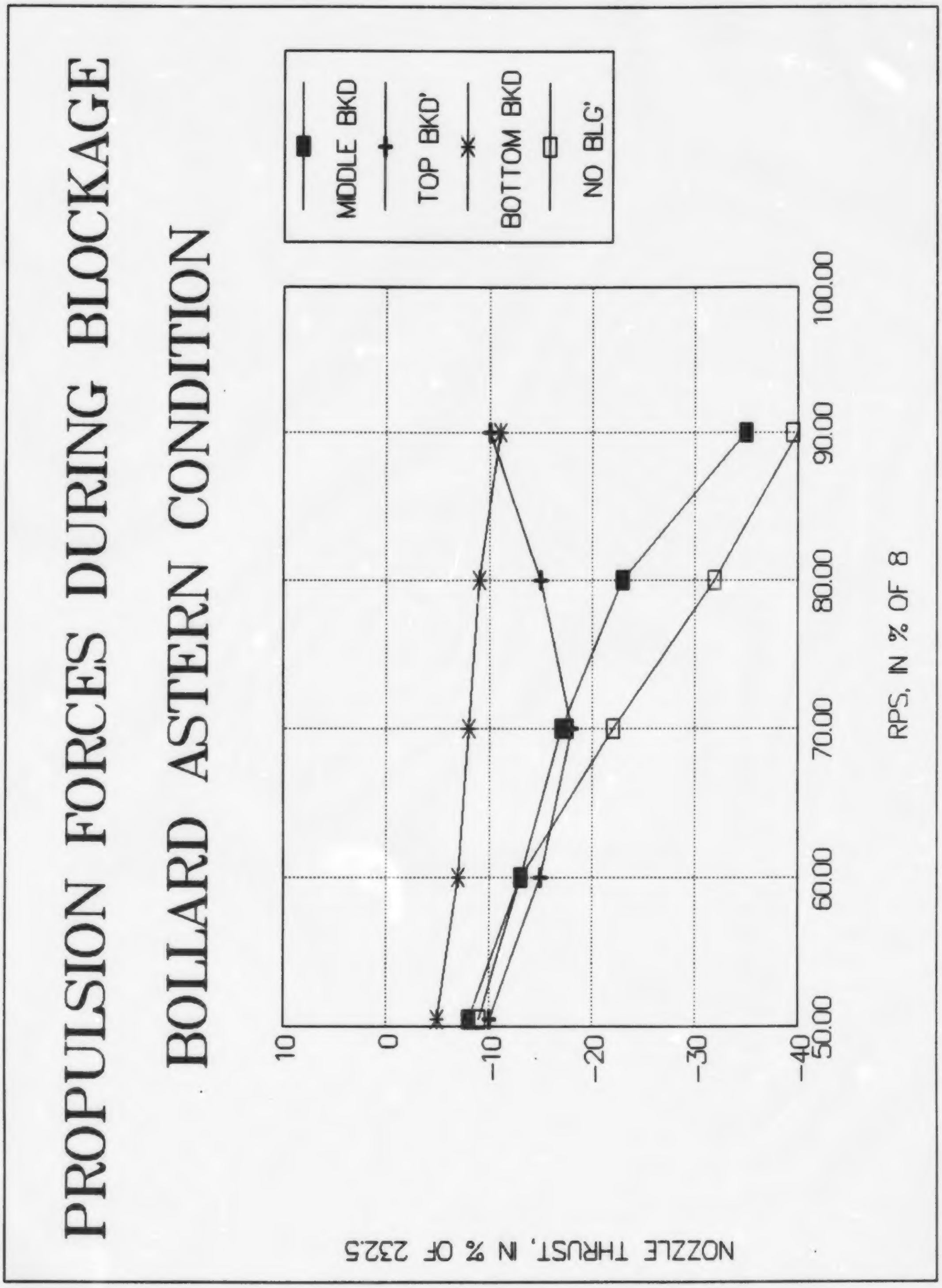

INFLUENCE OF THE BLOCKAGE ON
ON THE TOW PULL
TOW PULL, IN % OF 2325N
RPS, IN % OF MAXMUM
0
20
40
60
80
50.00
60.00
70.00
80.00
90.00
100.00
MIDDLE BKD
TOP BKD
BTM BKD
5 CM BKD
10CM BKD'



INFLUENCE OF SHIP SPEED ON TOTAL THRUST OF THE CENTERLINE SHAFT

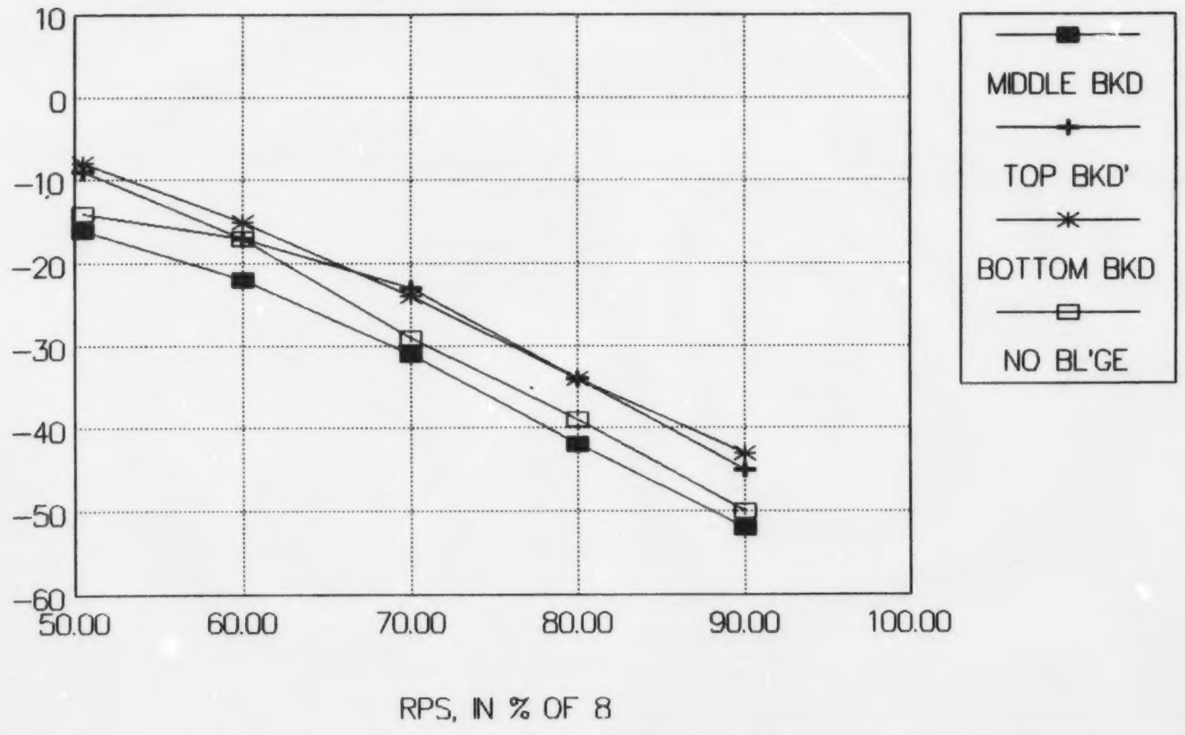


INFLUENCE OF SPEED ON THE THRUST/POWER RATIO IN BLOCKED CONDITION



PROPULSION FORCES DURING BLOCKAGE

BOLLARD ASTERN CONDITION



PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION

Figure 11.34

## PROPULSION FORCES DURING BLOCKAGE
## BOLLARD ASTERN CONDITION

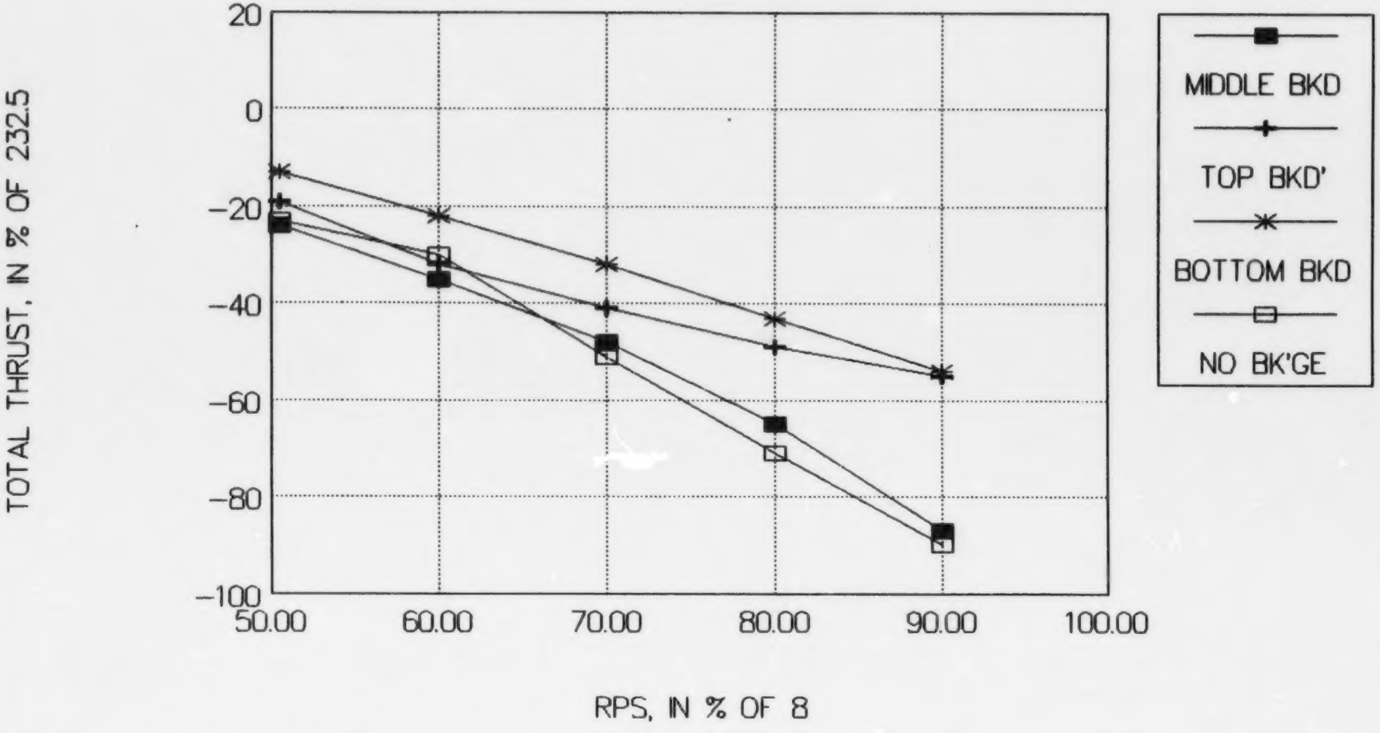
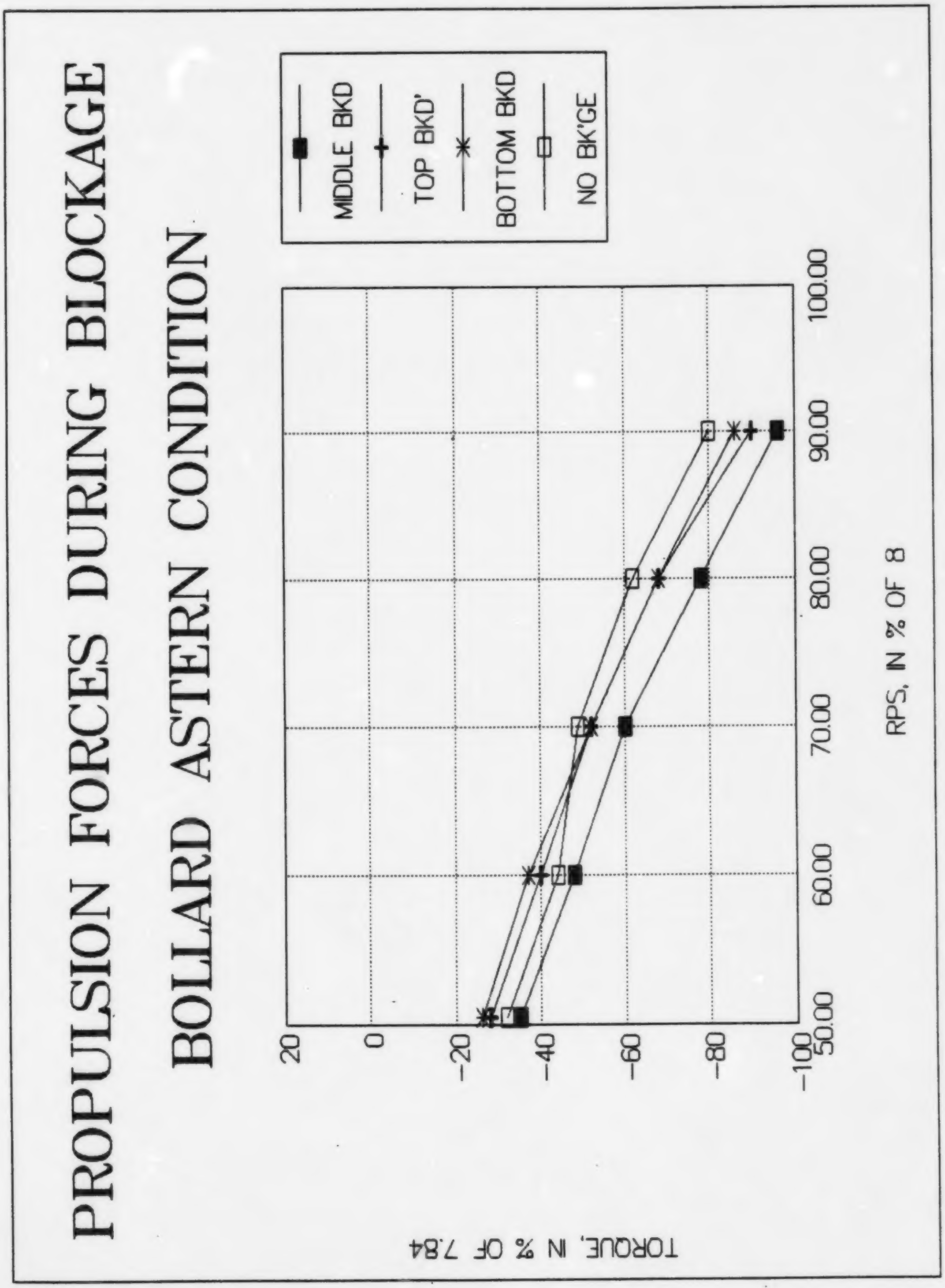
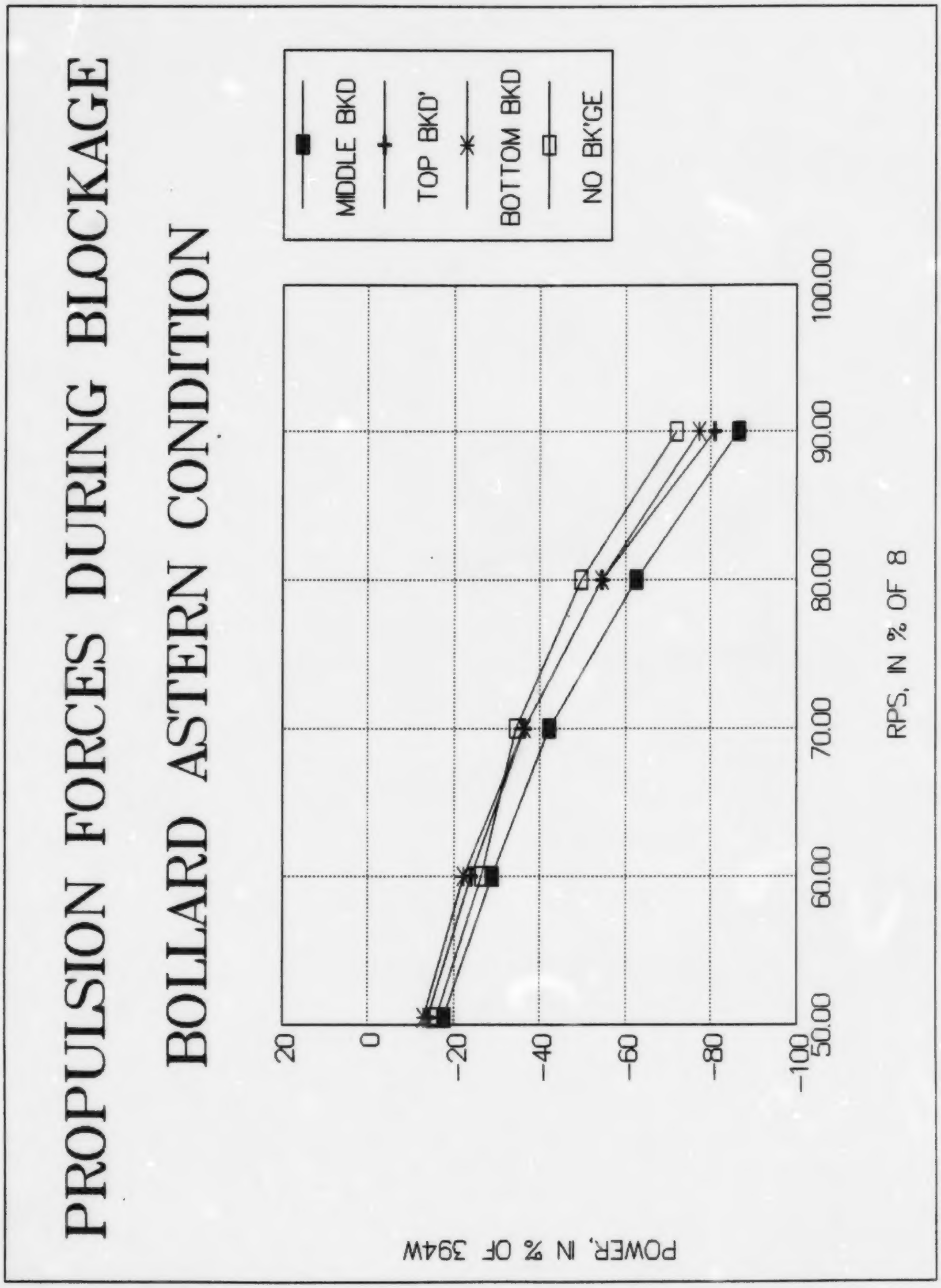


Figure 11.35


PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION
■ MIDDLE BKD
+ TOP BKD'
✳ BOTTOM BKD
□ NO BK'GE
TORQUE, IN % OF 7.84
20
0
−20
−40
−60
−80
−100
50.00
60.00
70.00
80.00
90.00
100.00
RPS, IN % OF 8


PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION
MIDDLE BKD
TOP BKD'
BOTTOM BKD
NO BK'GE
POWER, IN % OF 394W
RPS, IN % OF 8
20
0
−20
−40
−60
−80
−100
50.00
60.00
70.00
80.00
90.00
100.00

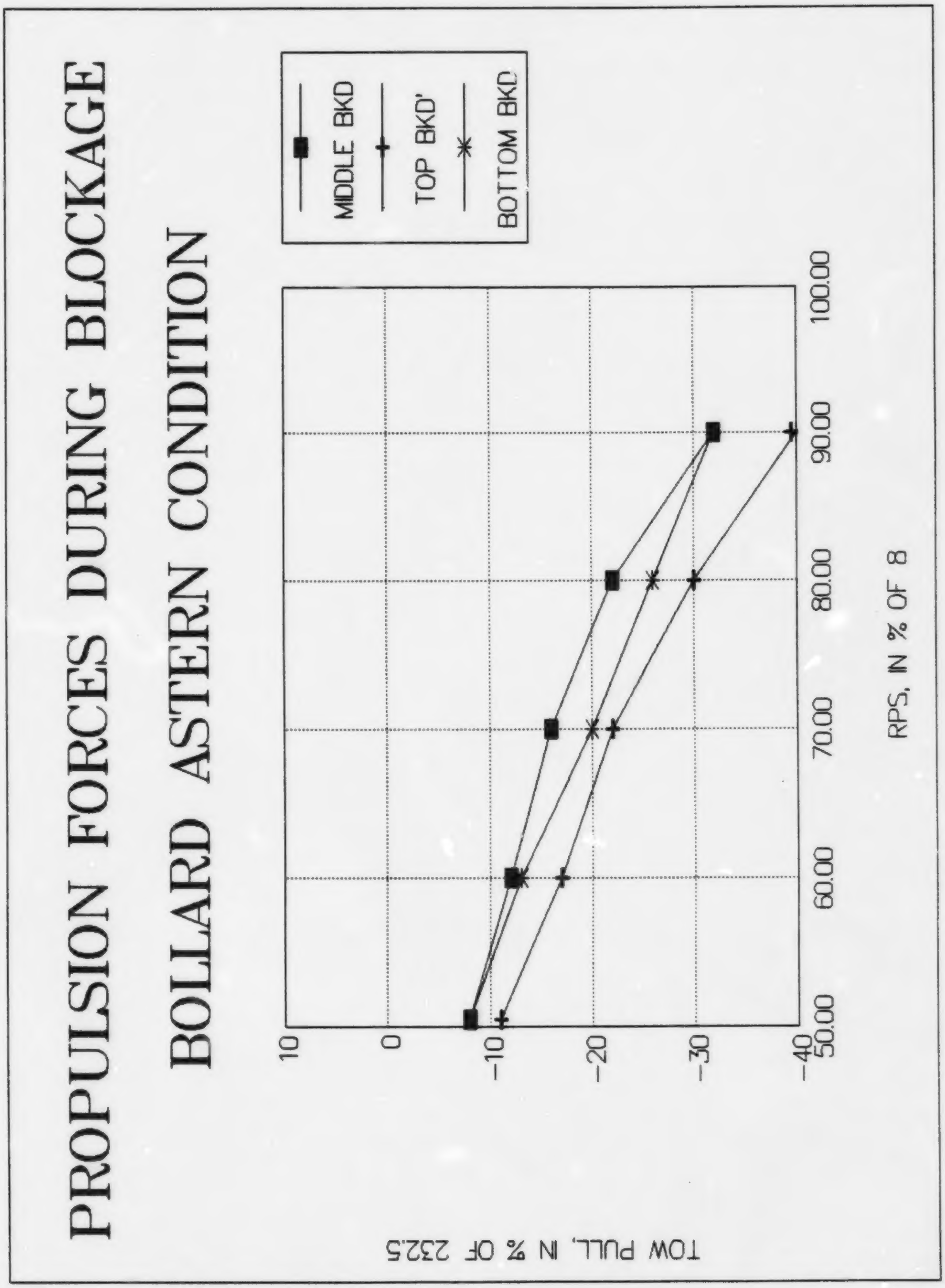

PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION
MIDDLE BKD
TOP BKD'
BOTTOM BKD
TOW PULL, IN % OF 232.5
10
0
-10
-20
-30
-40
50.00
60.00
70.00
80.00
90.00
100.00
RPS, IN % OF 8

Figure 11.38

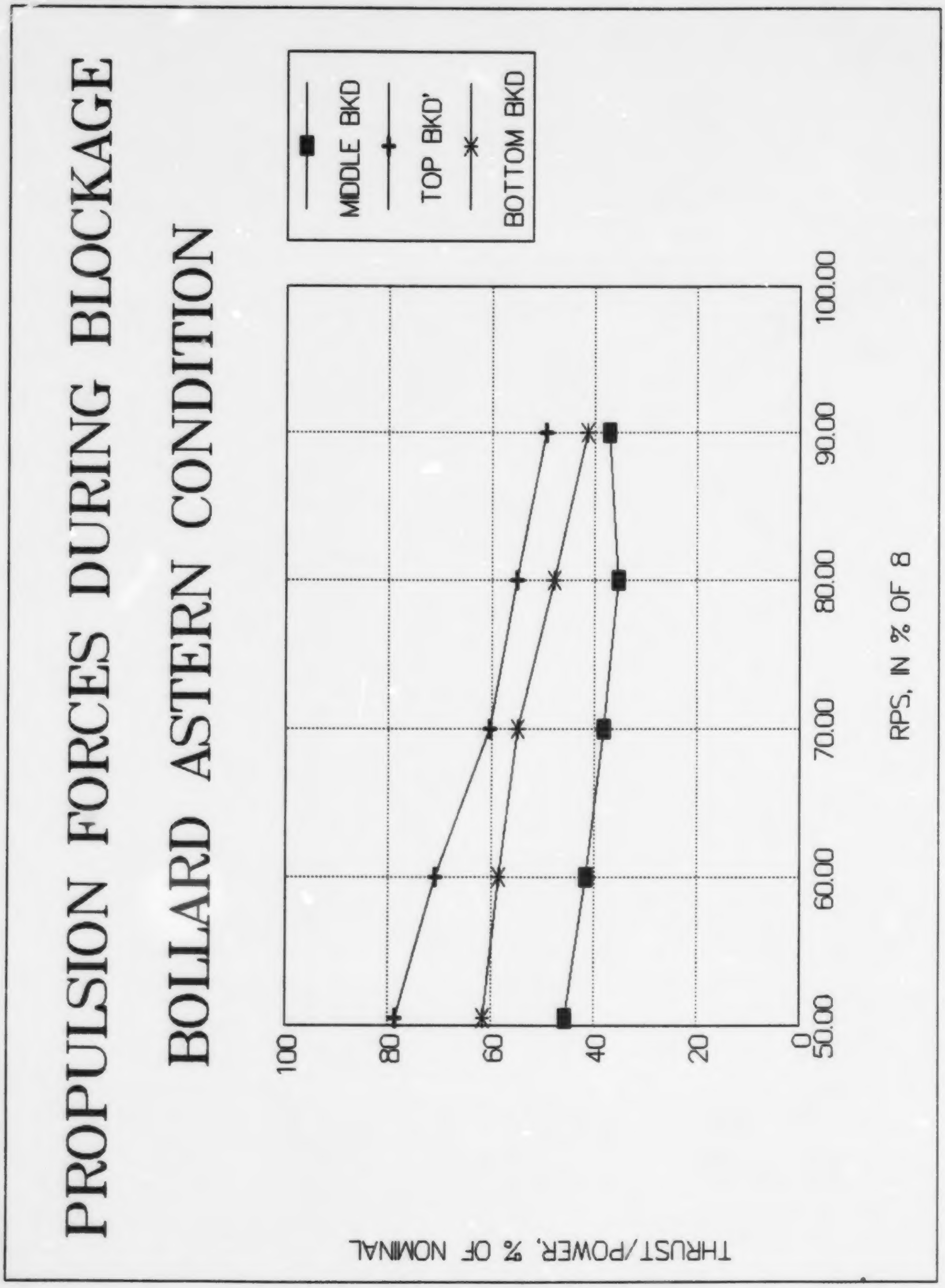
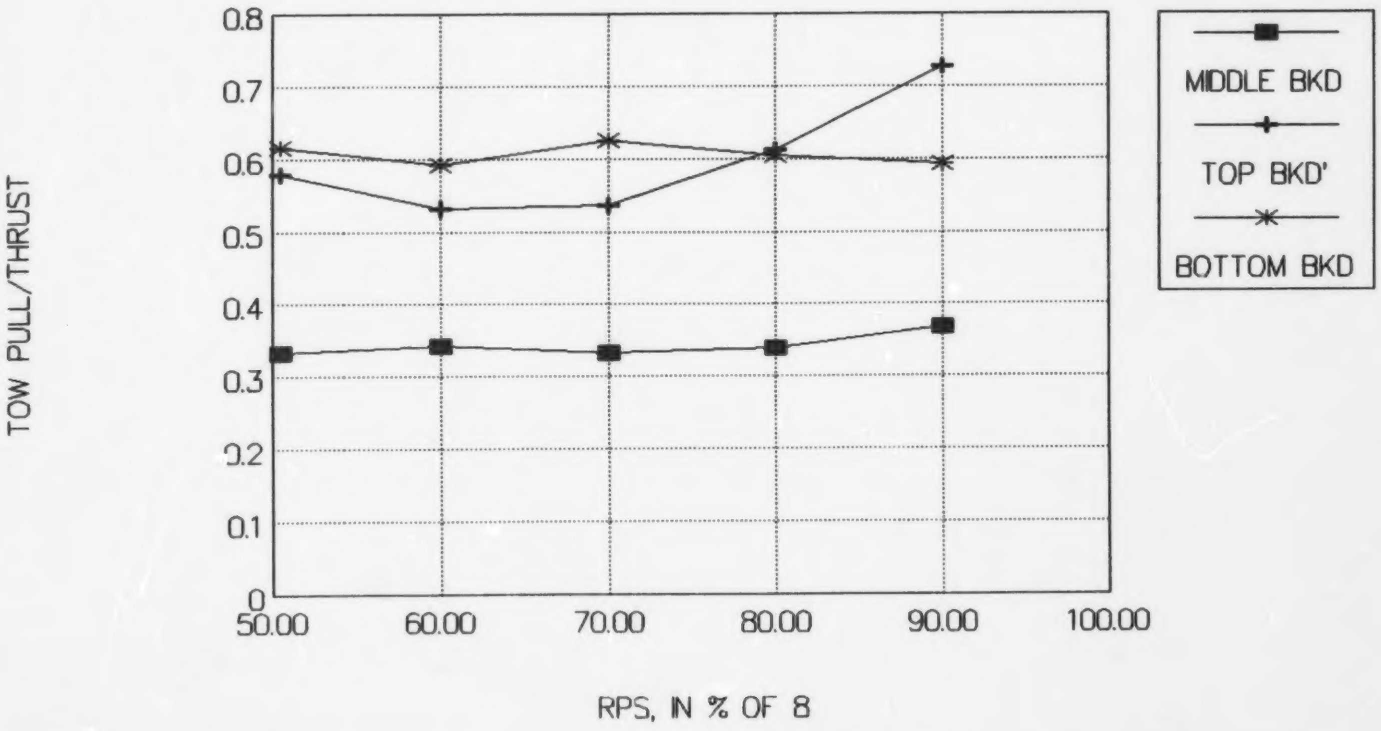
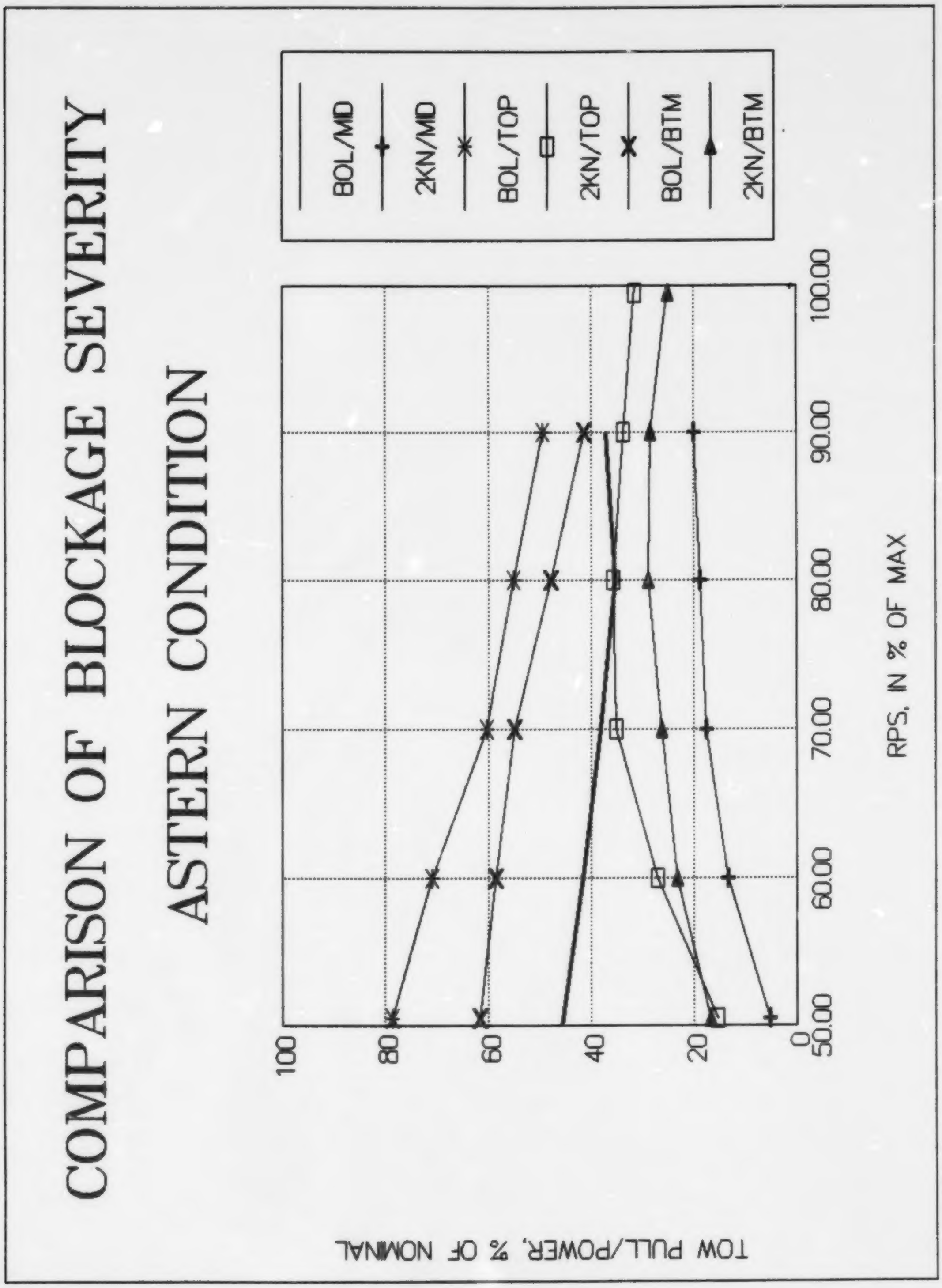

PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION
MIDDLE BKD
TOP BKD'
BOTTOM BKD
THRUST/POWER, % OF NOMINAL
RPS, IN % OF 8
0
20
40
60
80
100
50.00
60.00
70.00
80.00
90.00
100.00

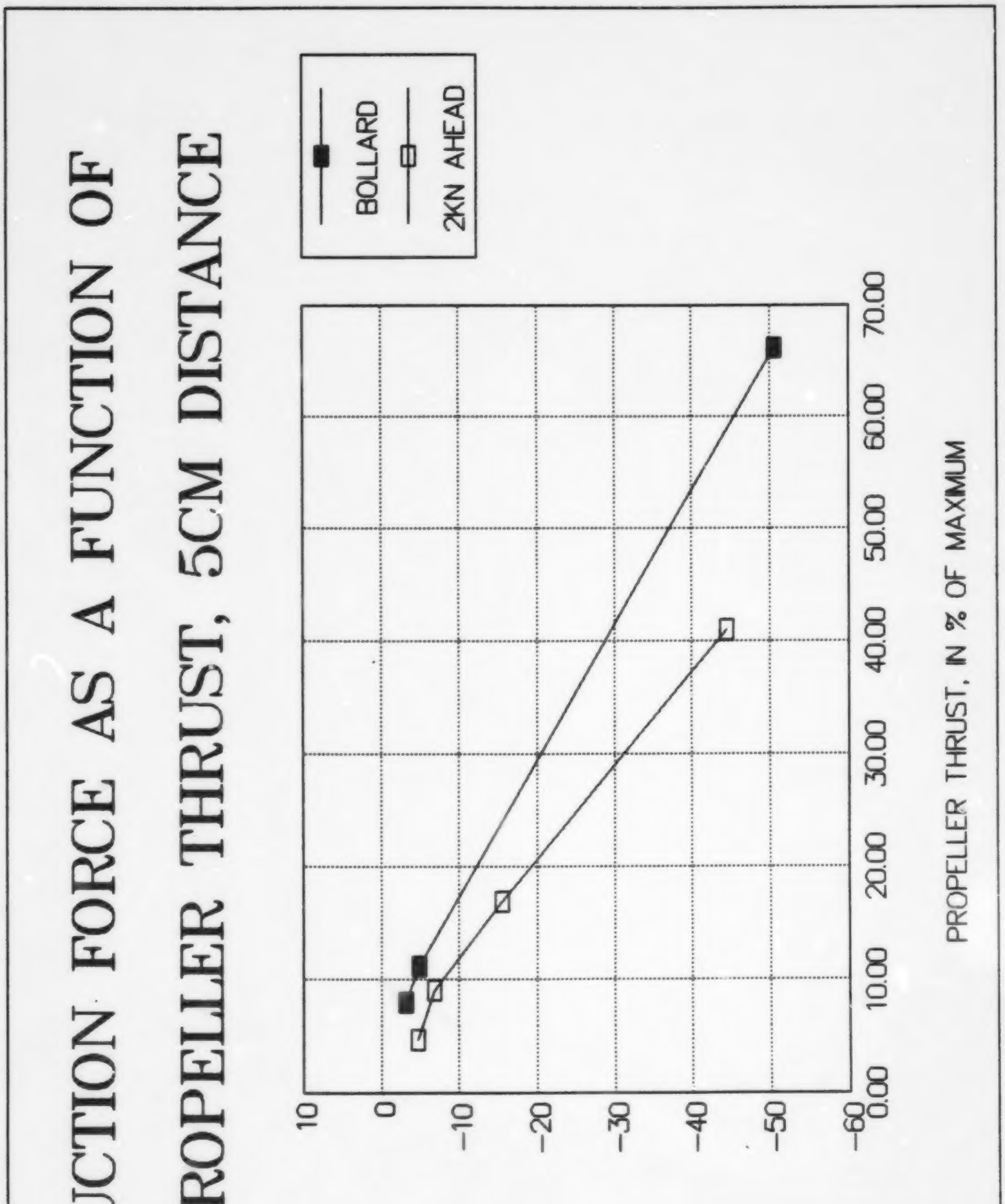
Figure 11.39

PROPULSION FORCES DURING BLOCKAGE
BOLLARD ASTERN CONDITION



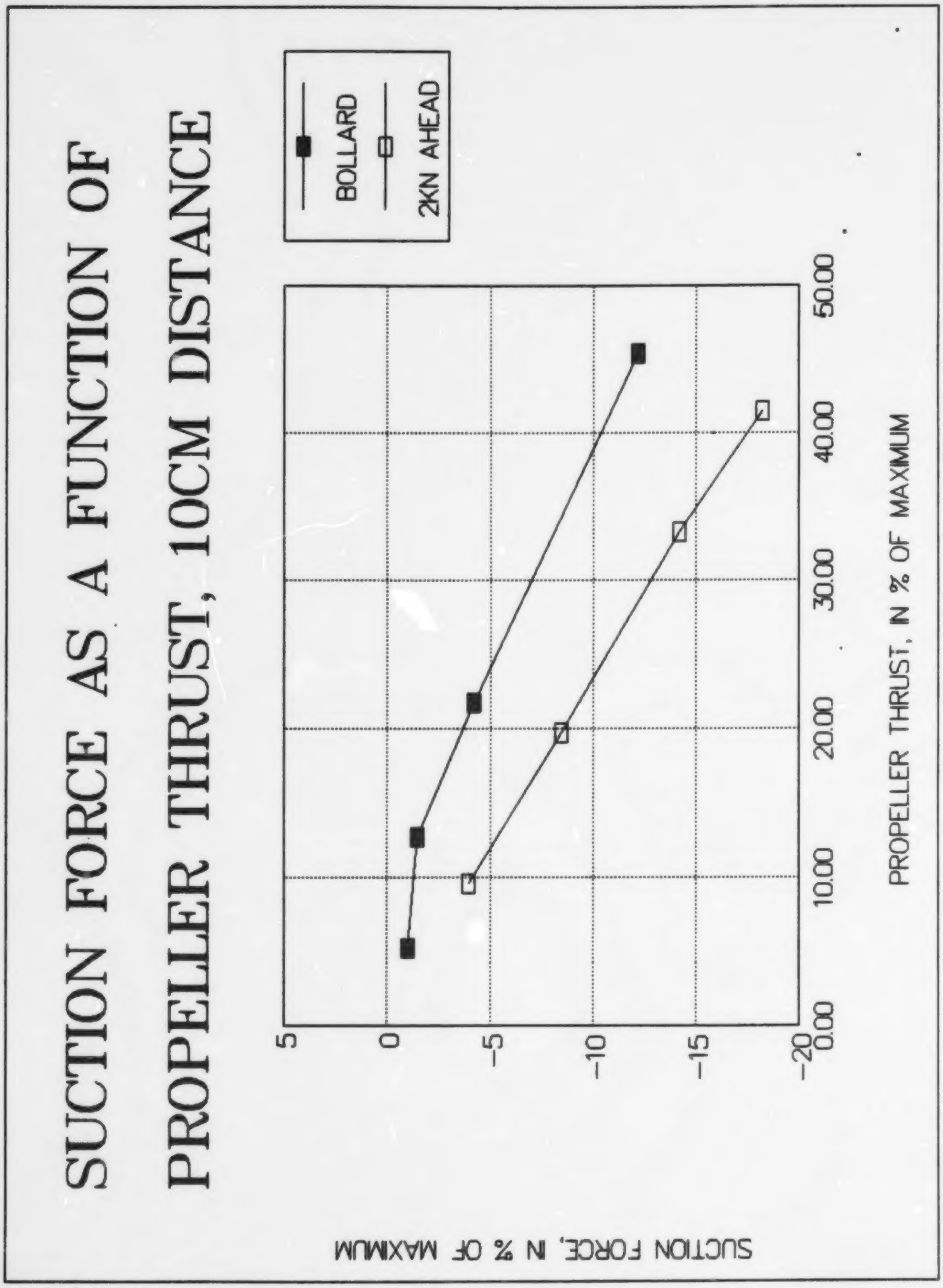


COMPARISON OF BLOCKAGE SEVERITY
ASTERN CONDITION



SUCTION FORCE AS A FUNCTION OF PROPELLER THRUST, 5CM DISTANCE

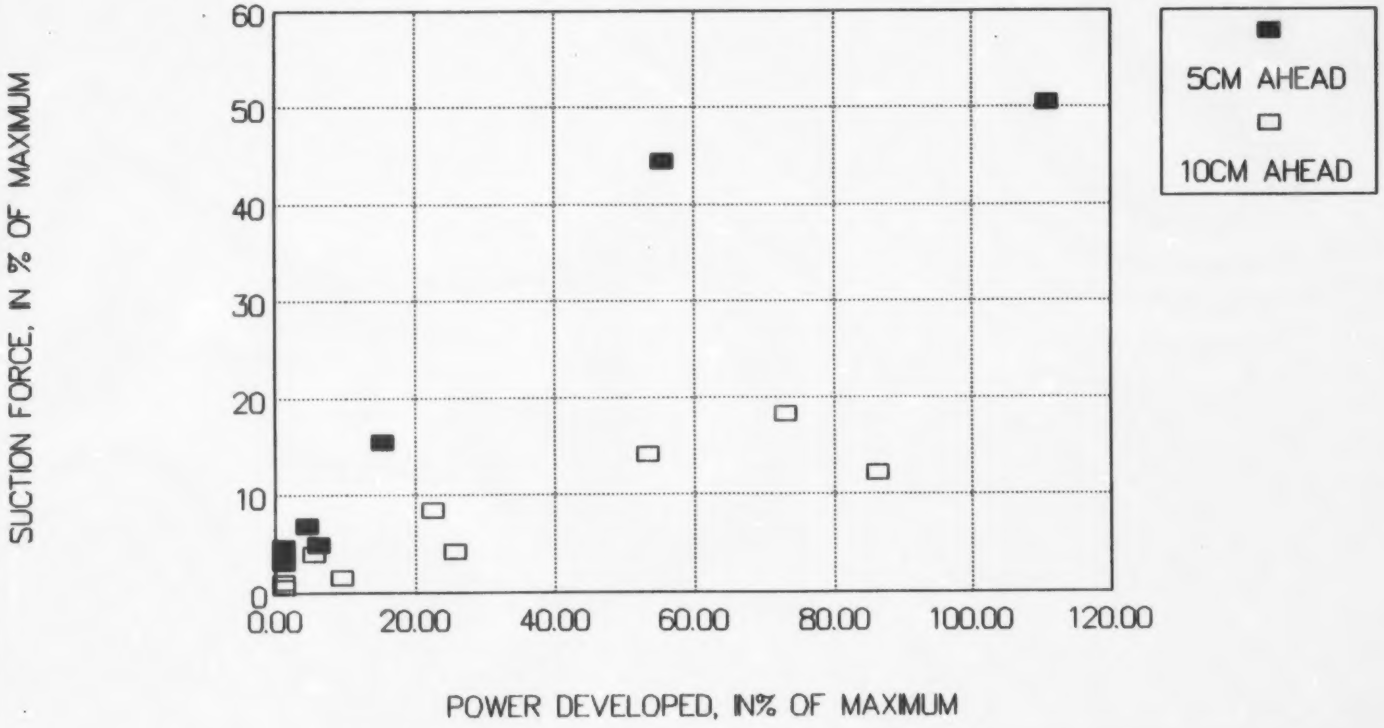
Figure 11.42



SUCTION FORCE AS A FUNCTION OF PROPELLER THRUST, 10CM DISTANCE

Figure 11.43

SUCTION FORCE AS A FUNCTION OF POWER AND DISTANCE TO PROPELLER – ALL DATA



NOZZLE THRUST VERSUS PROP THRUST
BOLLARD AHEAD, MID FWD BLOCKED

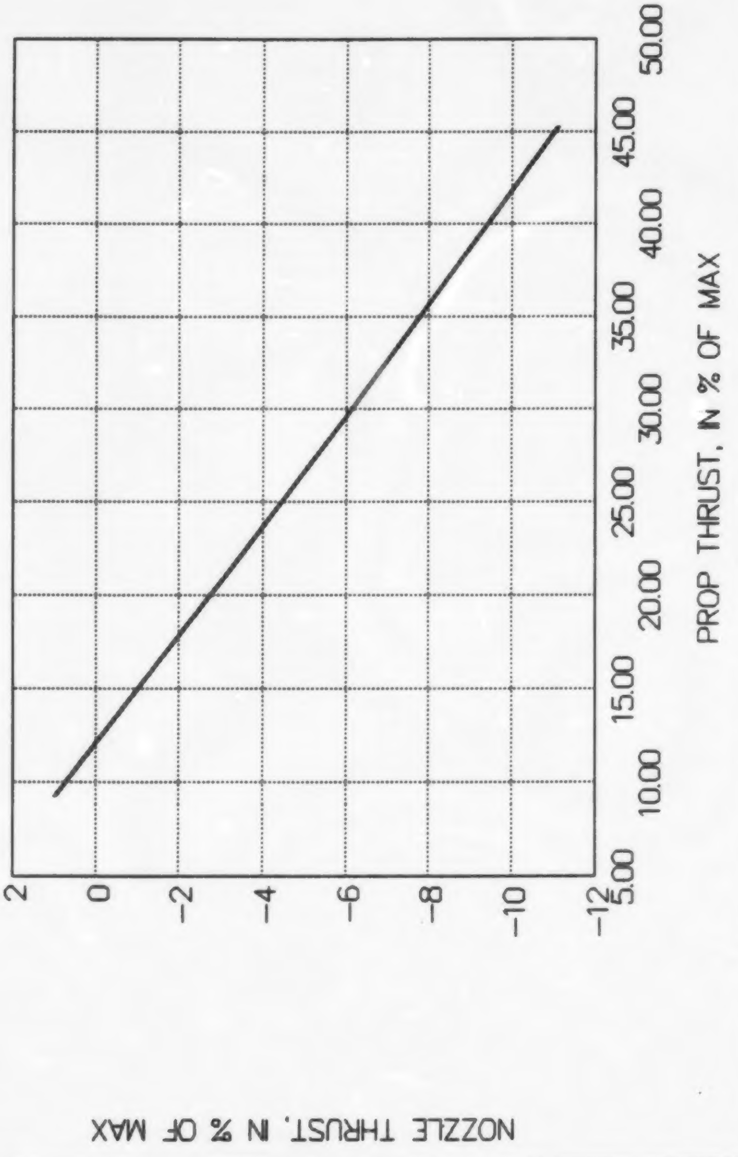
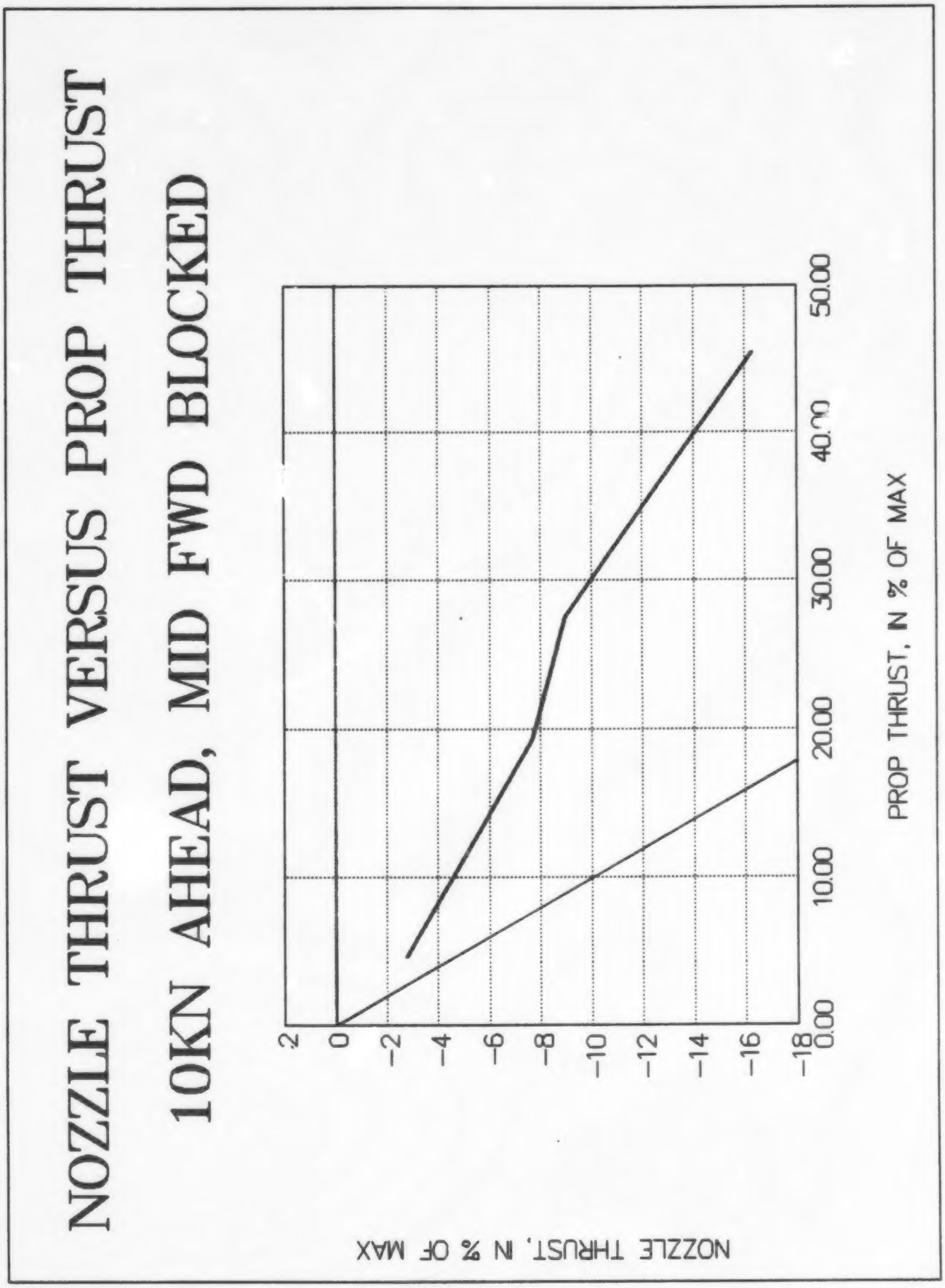


Figure 11.45



NOZZLE THRUST VERSUS PROP THRUST
10KN AHEAD, MID FWD BLOCKED

TABLE 11.5
VIBRATION LEVELS DURING THE BLOCKAGE CONDITION

| RPS | THRUST NEWTONS | RMS | RMS/ THRUST | TORQUE NM | RMS | RMS/ TORQUE | NOZZLE NM | RMS | RMS/BM |
|---|---|---|---|---|---|---|---|---|---|
| | BOLLARD AHEAD, NO BLOCKAGE | | | | | | | | |
| 7.10 | 83.80 | 4.53 | 5.41 | 5.48 | 0.54 | 9.85 | 20.11 | 0.76 | 3.78 |
| 5.70 | 60.50 | 4.20 | 6.94 | 3.54 | 0.45 | 12.71 | 14.96 | 1.18 | 7.89 |
| 5.45 | 46.56 | 3.61 | 7.75 | 2.59 | 0.41 | 15.83 | 9.92 | 0.62 | 6.25 |
| 7.10 | 84.10 | 5.68 | 6.75 | 5.35 | 0.52 | 9.72 | 22.26 | 1.20 | 5.39 |
| | BLOCKAGE MIDDLE FWD | | | | | | | | |
| 3.20 | 23.62 | 4.56 | 19.31 | -1.43 | 0.41 | 28.67 | 4.88 | 1.02 | 20.90 |
| 4.90 | 55.00 | 7.06 | 12.84 | 0.48 | 0.46 | 95.83 | 11.41 | 1.38 | 12.09 |
| 5.76 | 79.76 | 9.79 | 12.27 | 1.87 | 0.52 | 27.81 | 19.56 | 2.05 | 10.48 |
| 7.06 | 118.20 | 13.47 | 11.40 | 3.98 | 0.65 | 16.33 | 30.38 | 3.23 | 10.63 |
| | BLOCKAGE 5CM BOLLARD | | | | | | | | |
| 2.73 | 25.91 | 5.80 | 22.39 | 1.39 | 0.19 | 13.67 | -3.46 | 0.24 | 6.94 |
| 7.85 | 153.90 | 10.81 | 7.02 | 8.84 | 0.74 | 8.37 | 4.73 | 5.46 | 115.43 |
| 6.06 | 90.98 | 9.80 | 10.77 | 5.30 | 0.35 | 6.60 | -8.44 | 4.28 | 50.71 |
| | BLOCKAGE 5CM 2KNOTS AHEAD | | | | | | | | |
| 2.42 | 20.92 | 5.68 | 27.15 | 11.51 | 0.28 | 2.41 | 2.04 | 0.36 | 17.70 |
| 4.14 | 39.36 | 6.30 | 16.01 | 2.32 | 0.31 | 13.53 | -6.40 | 0.55 | 8.61 |
| 6.28 | 95.30 | 10.52 | 11.04 | 5.53 | 0.42 | 7.59 | -4.87 | 3.62 | 74.33 |
| 7.82 | 148.30 | 12.66 | 8.54 | 8.56 | 0.56 | 6.54 | 5.80 | 5.72 | 98.62 |
| | BLOCKAGE 10CM AHEAD, BOLLARD | | | | | | | | |
| 0.17 | 12.01 | 4.63 | 38.55 | 0.65 | 0.12 | 18.46 | -2.20 | 0.20 | 9.09 |
| 3.42 | 29.53 | 5.53 | 18.73 | 1.72 | 0.19 | 11.05 | -6.79 | 0.19 | 2.80 |
| 5.12 | 50.56 | 5.63 | 11.14 | 3.14 | 0.27 | 8.60 | -12.77 | 0.62 | 4.86 |
| 7.93 | 105.60 | 6.00 | 5.68 | 6.81 | 0.26 | 3.82 | -28.69 | 1.51 | 5.26 |

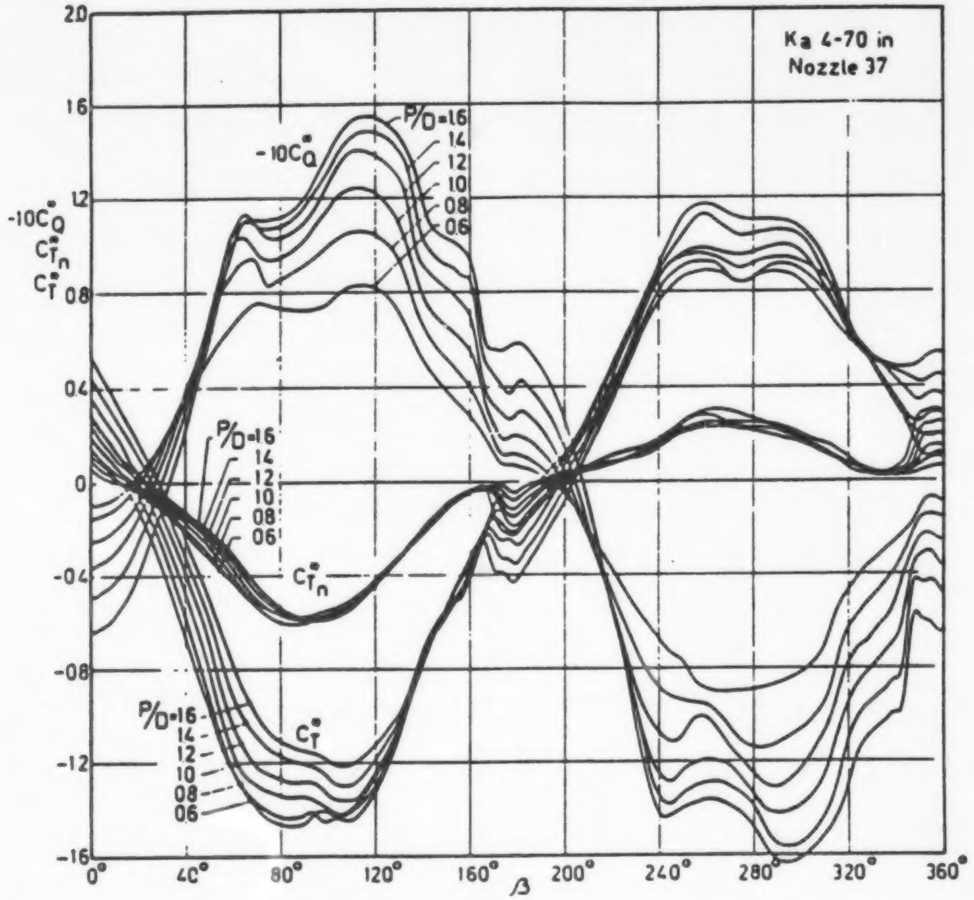


Fig. Open-water test results with Ka 4-70 screw series in nozzle no. 37 in the four quadrants

Figure 11.46b

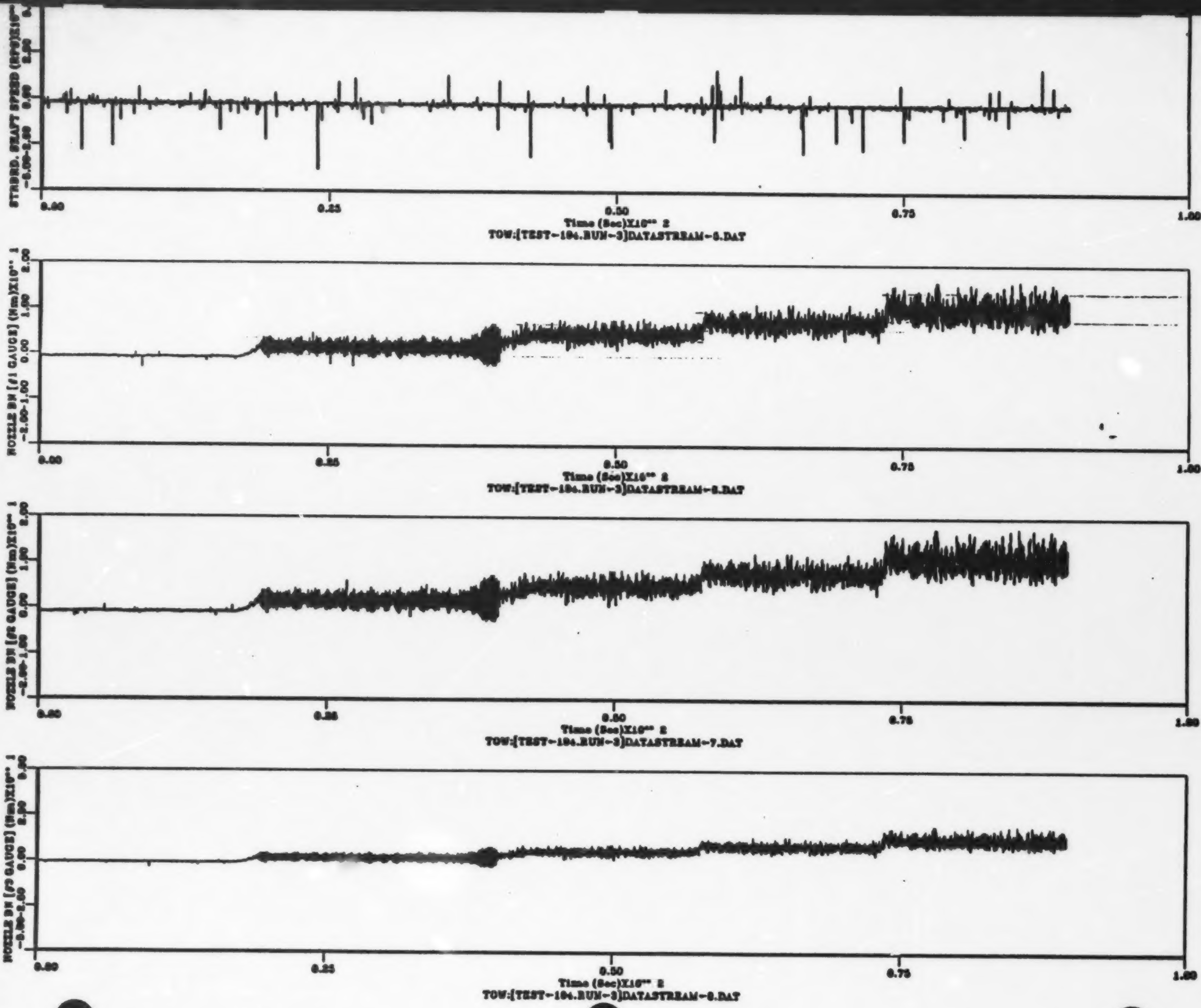


Figure 11.46c

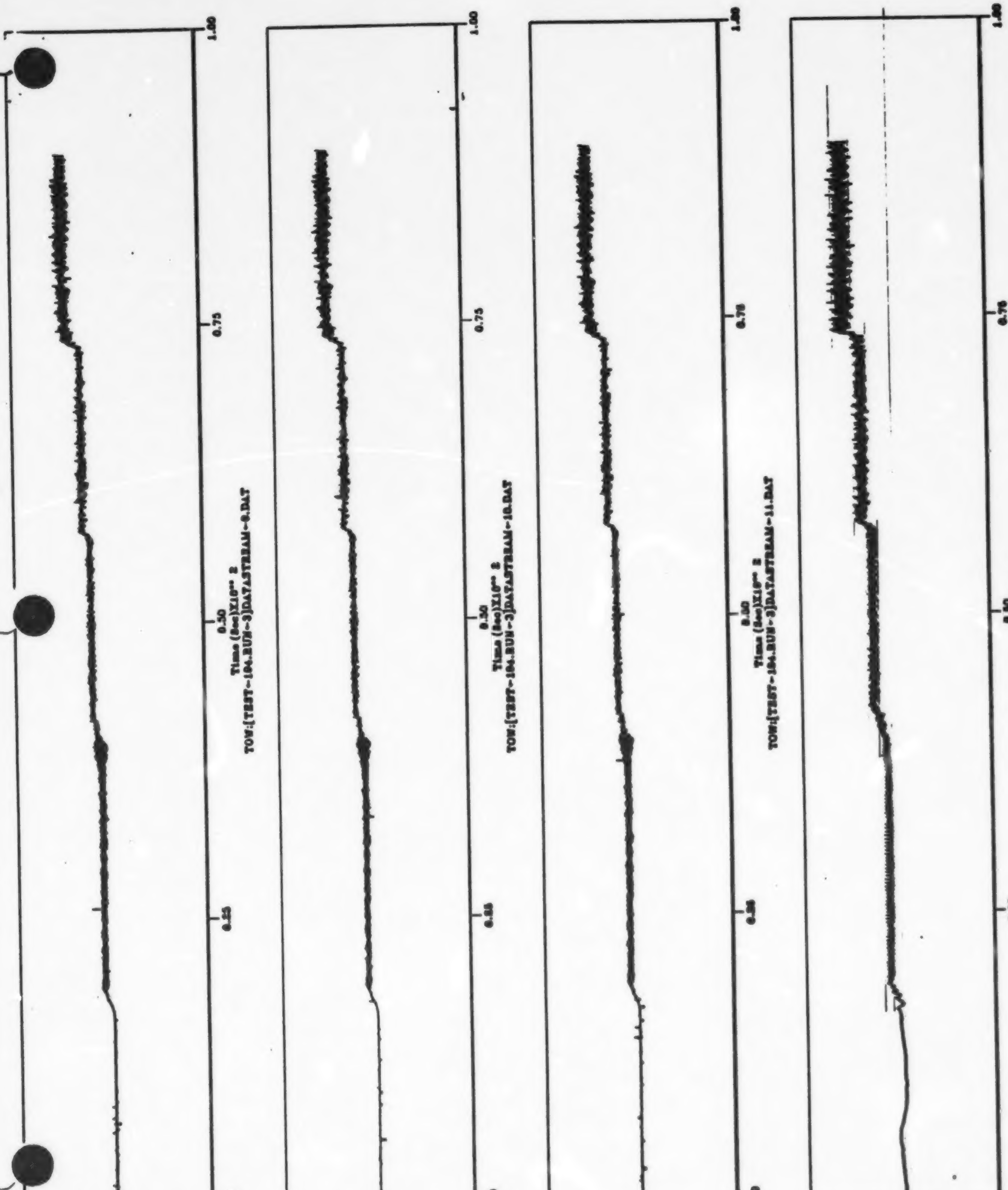


Figure 11.46d

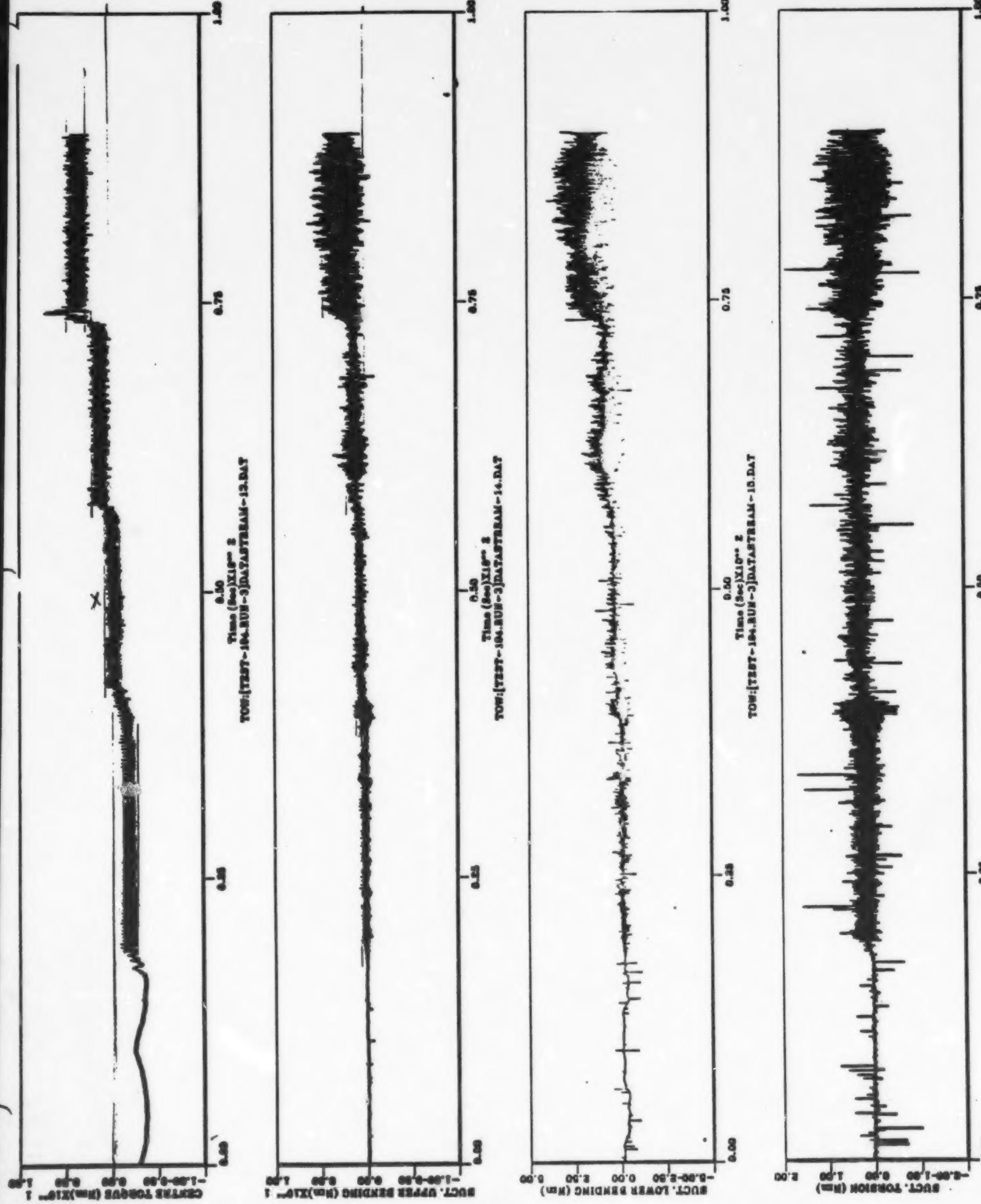


Figure 11.47

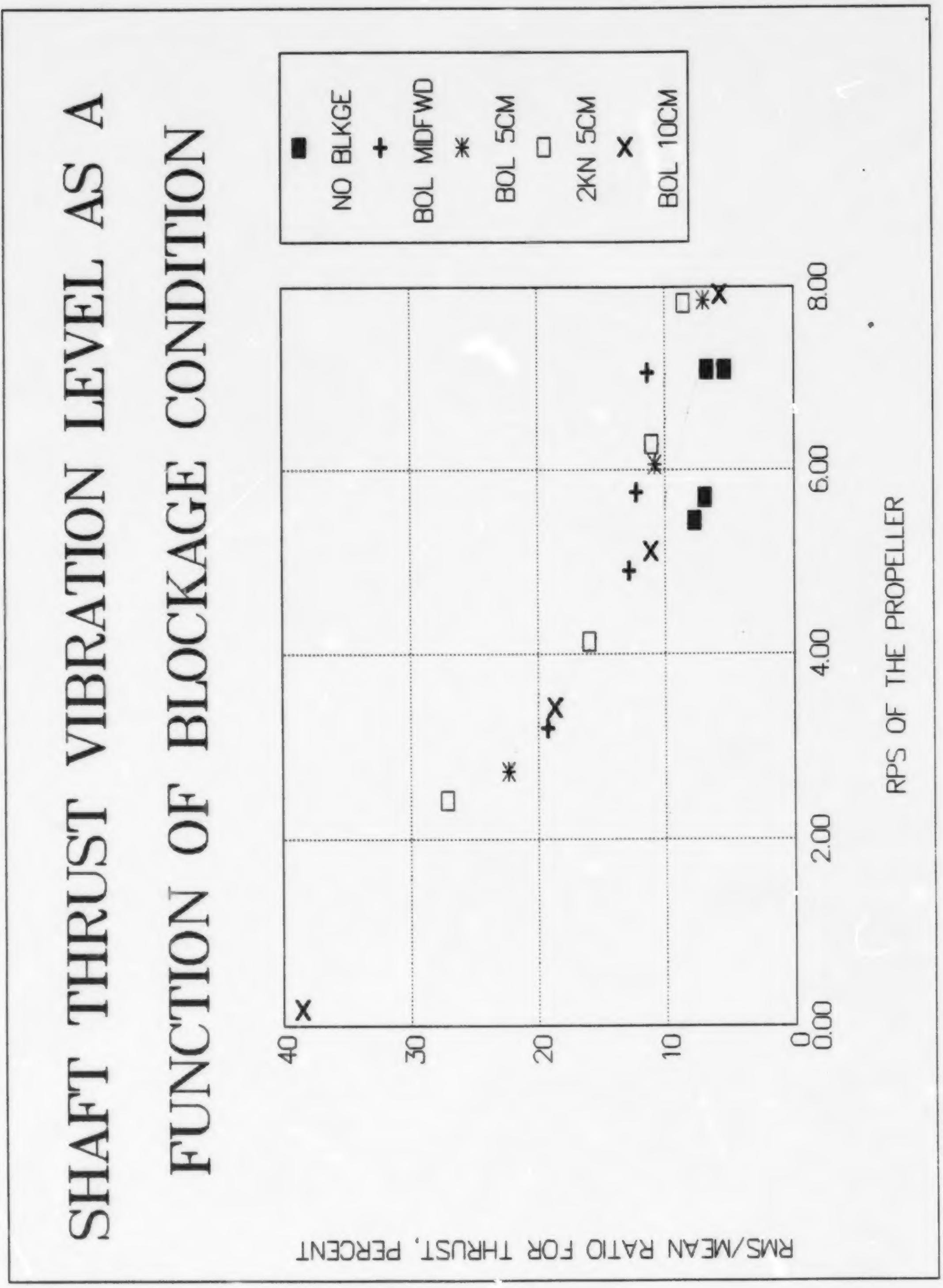

SHAFT THRUST VIBRATION LEVEL AS A FUNCTION OF BLOCKAGE CONDITION
RMS/MEAN RATIO FOR THRUST, PERCENT
RPS OF THE PROPELLER
0
10
20
30
40
0.00
2.00
4.00
6.00
8.00
■ NO BLKGE
+ BOL MIDFWD
* BOL 5CM
□ 2KN 5CM
X BOL 10CM

Figure 11.48

SHAFT TORQUE VIBRATION LEVEL AS A FUNCTION OF BLOCKAGE CONDITION

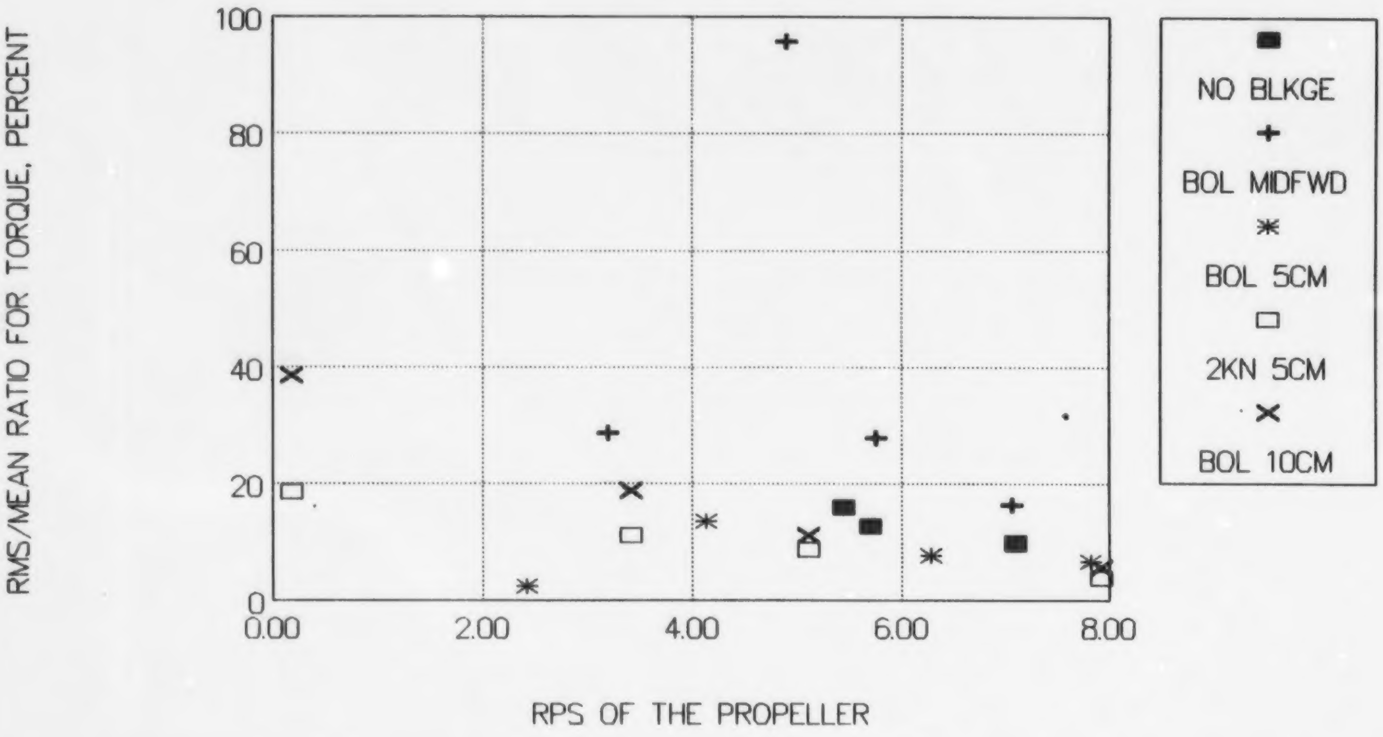


Figure 11.49

# NOZZLE BENDING VIBRATION LEVEL AS A FUNCTION OF BLOCKAGE CONDITION

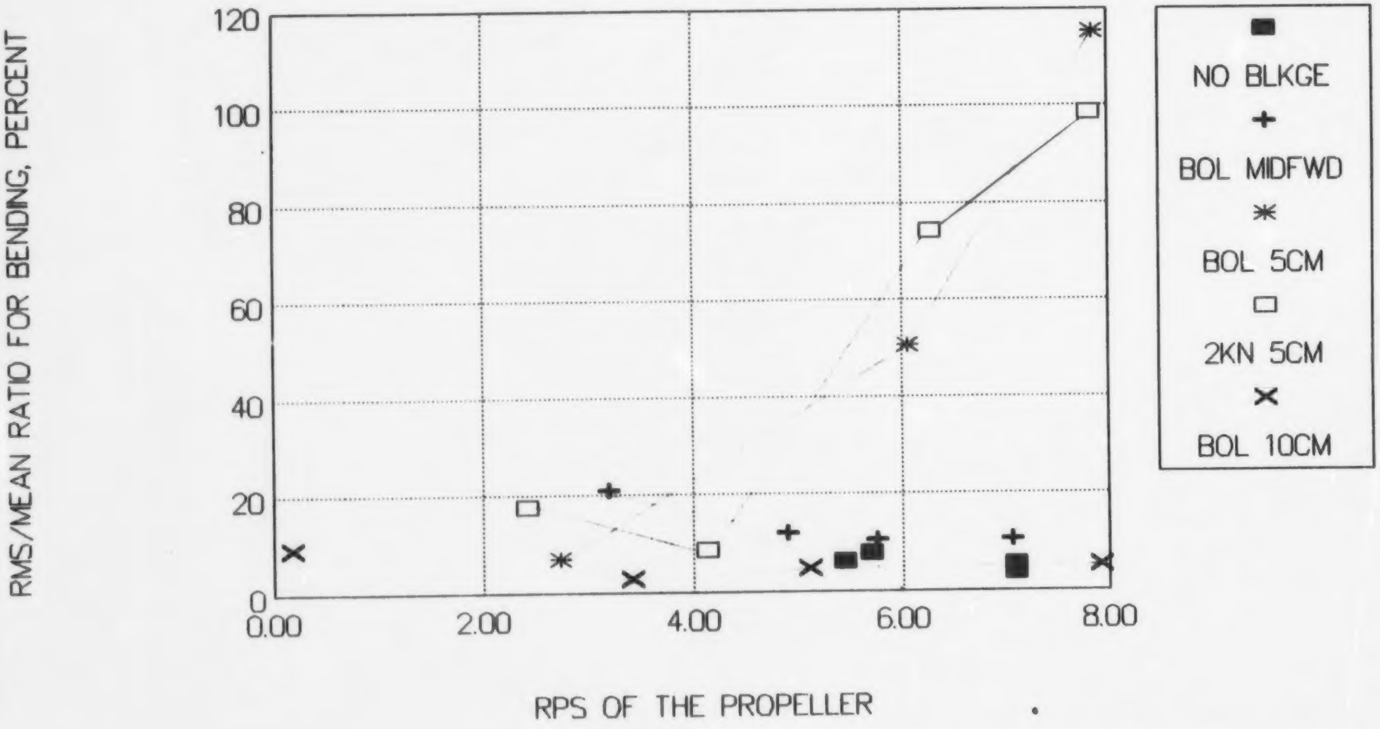
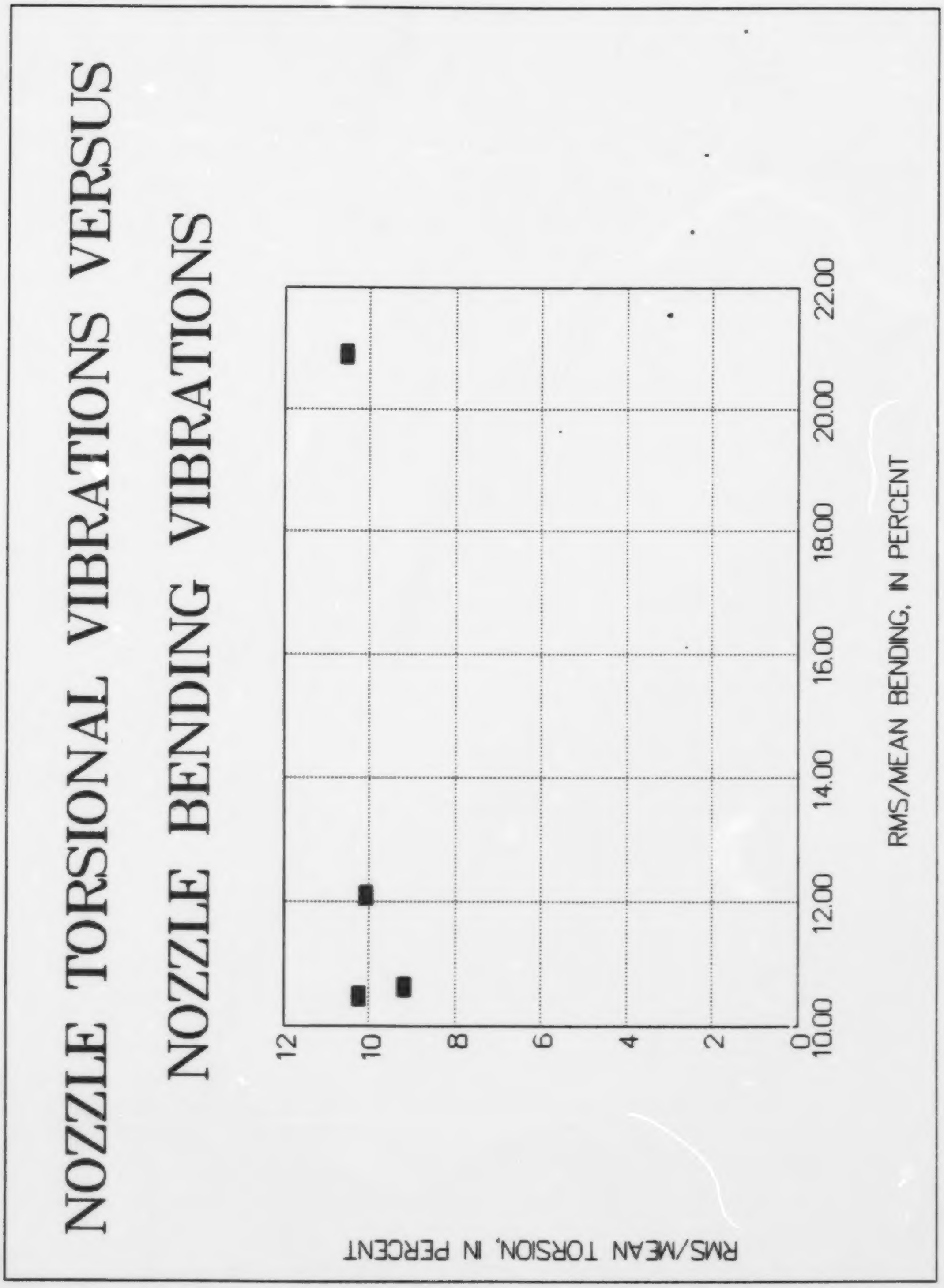
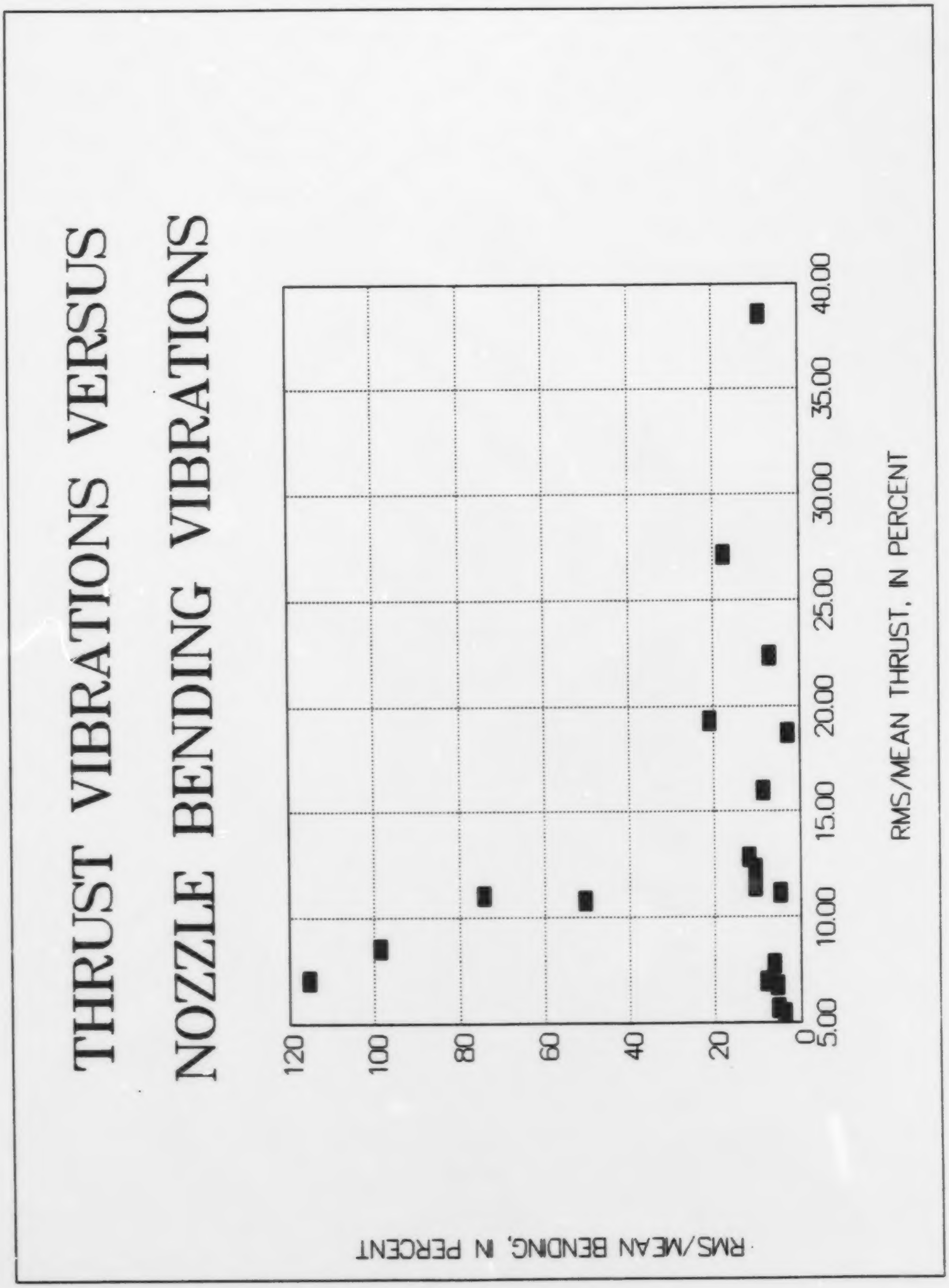


Figure 11.50

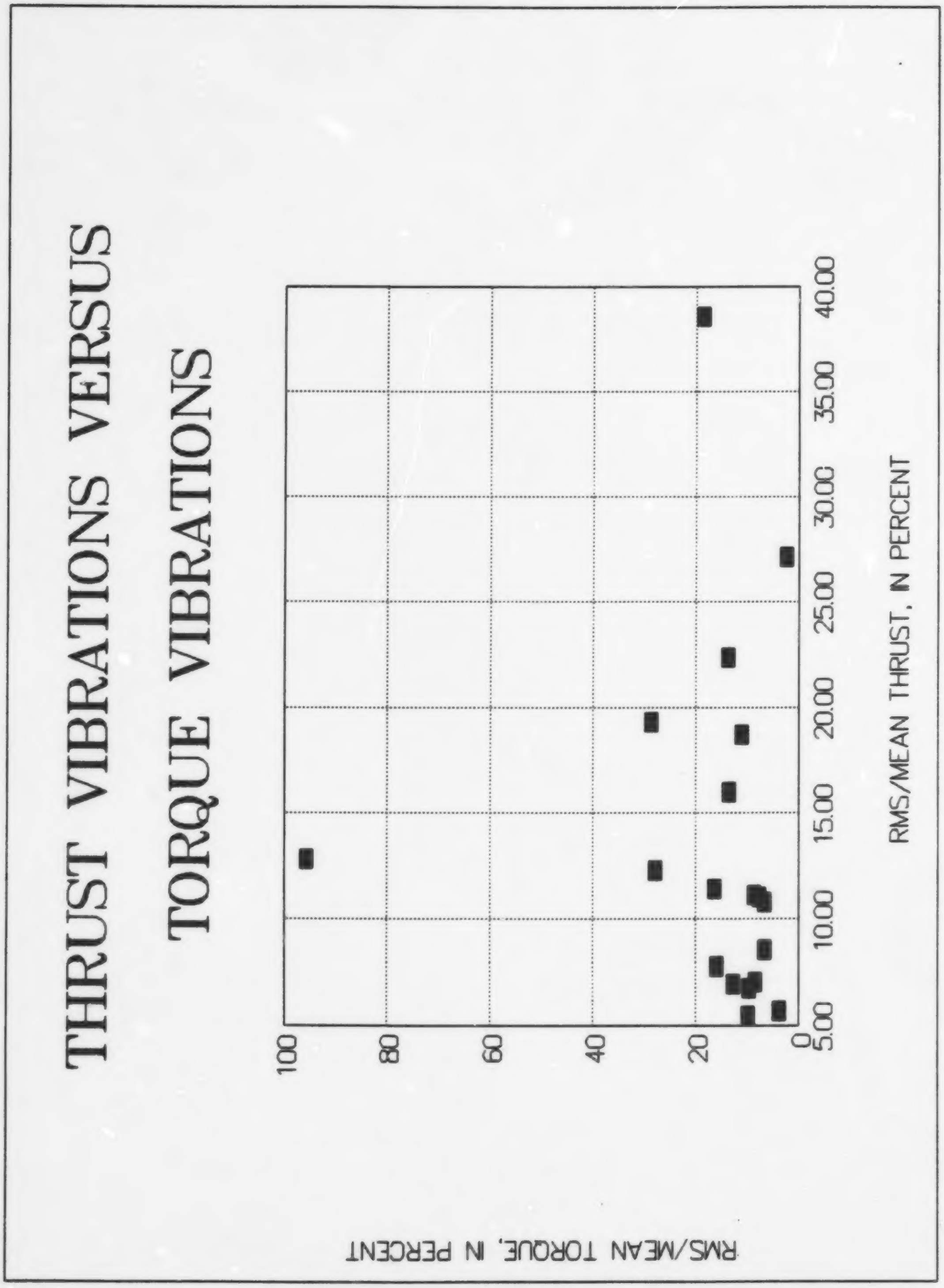


NOZZLE TORSIONAL VIBRATIONS VERSUS NOZZLE BENDING VIBRATIONS



THRUST VIBRATIONS VERSUS NOZZLE BENDING VIBRATIONS

Figure 11.52



THRUST VIBRATIONS VERSUS TORQUE VIBRATIONS

Figure 11.53

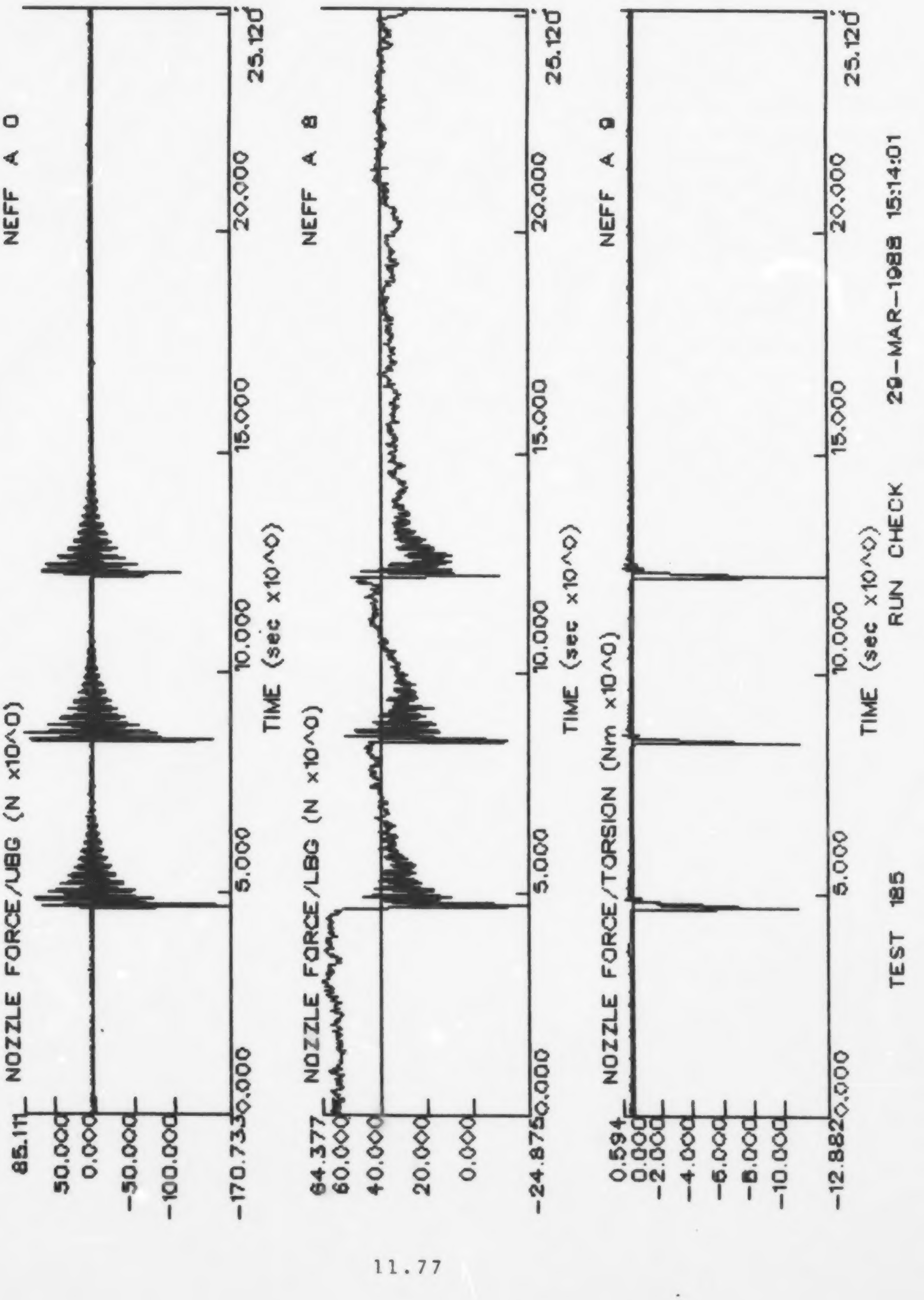

NOZZLE FORCE/UBG (N x10^0)
NEFF A 0
85.111
50.000
0.000
-50.000
-100.000
-170.733
0.000
5.000
10.000
15.000
20.000
25.120
TIME (sec x10^0)
NOZZLE FORCE/LBG (N x10^0)
NEFF A 8
64.377
60.000
40.000
20.000
0.000
-24.875
0.000
5.000
10.000
15.000
20.000
25.120
TIME (sec x10^0)
NOZZLE FORCE/TORSION (Nm x10^0)
NEFF A 9
0.594
0.000
-2.000
-4.000
-6.000
-8.000
-10.000
-12.882
0.000
5.000
10.000
15.000
20.000
25.120
TIME (sec x10^0)
TEST 185
RUN CHECK
29-MAR-1988 15:14:01

Figure 11.54

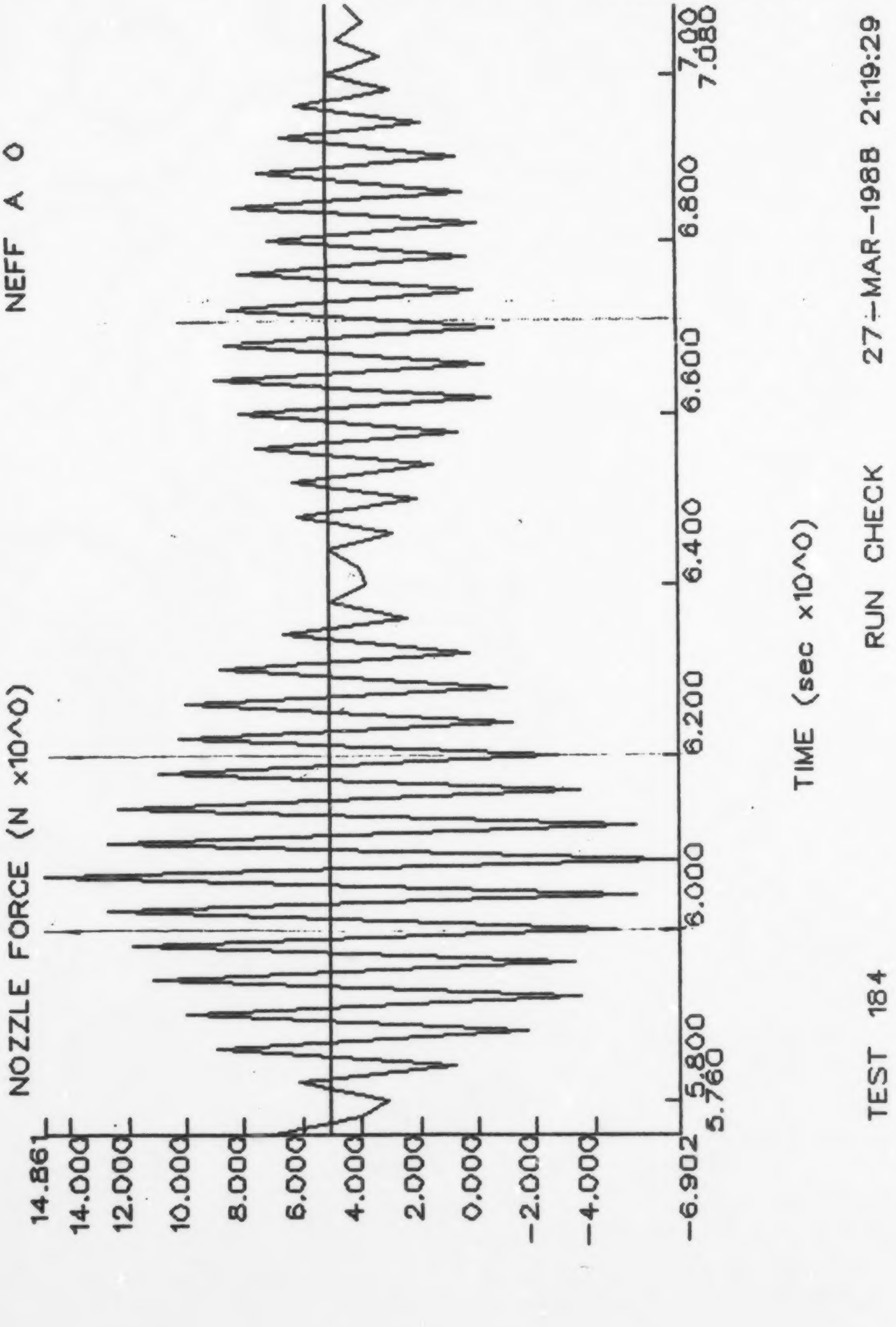

NOZZLE FORCE (N x10^0)
NEFF A 0
14.861
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
-2.000
-4.000
-6.902
5.760
5.800
6.000
6.200
6.400
6.600
6.800
7.000
7.080
TIME (sec x10^0)
TEST 184
RUN CHECK
27-MAR-1988 21:19:29

Figure 11.55

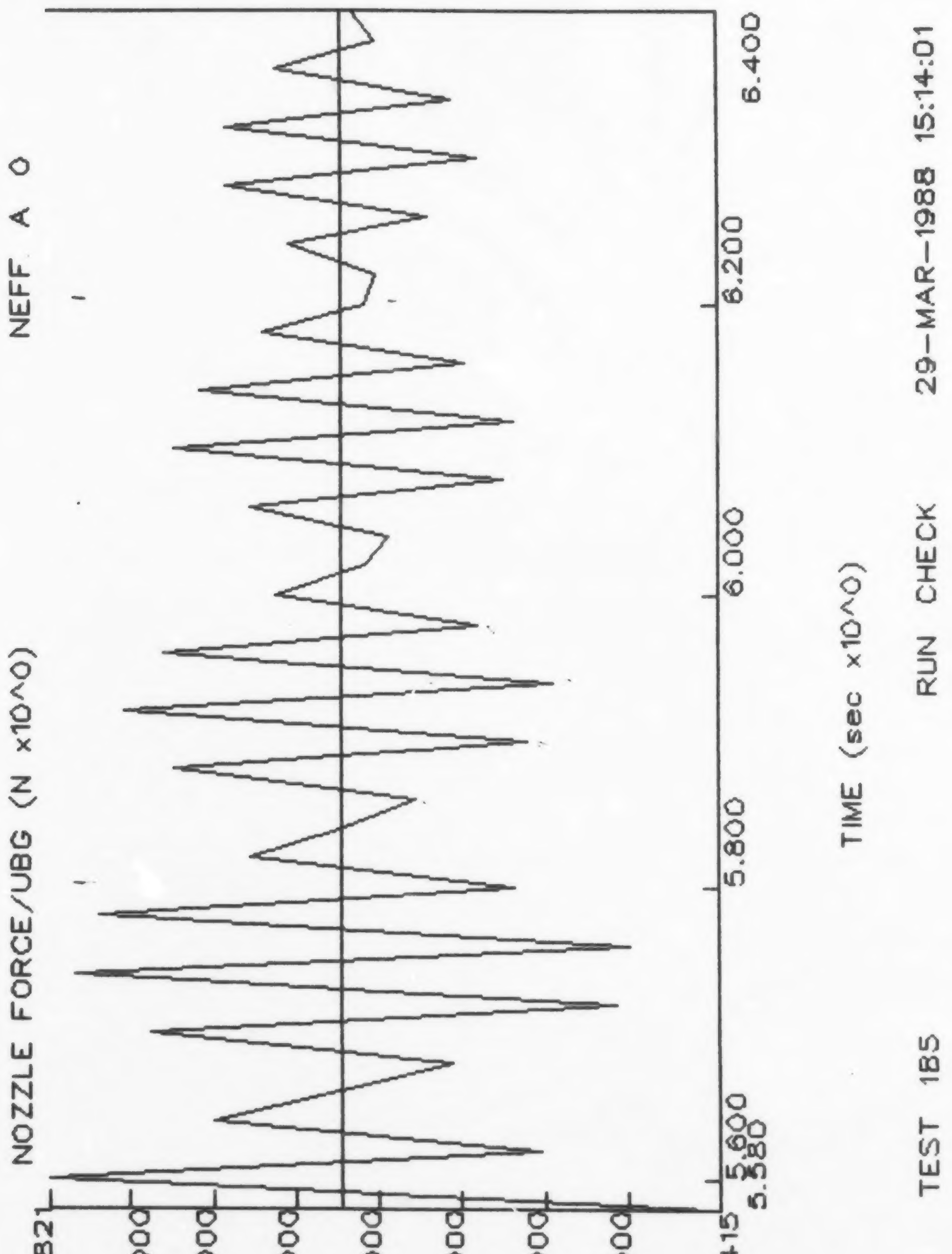

NOZZLE FORCE/UBG (N x10^0)
NEFF A 0
19.821
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.415
5.580
5.600
5.800
6.000
6.200
6.400
TIME (sec x10^0)
TEST 1B5
RUN CHECK
29-MAR-1988 15:14:01

Figure 11.56

THIS IS THE PROCEDURE TO COMPUTE THE TWO ORIGINAL FREQUENCIES FROM THE BEAT FREQUENCY DIAGRAM

$T := 0, 0.0025 \,..\, 1$

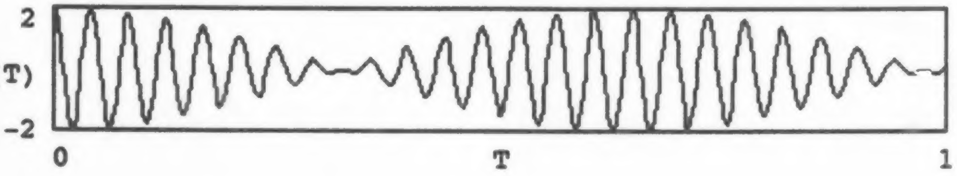
$F1 := 24.616 \qquad F2 := 23.077$

$\Omega 1 := F1 \cdot 2 \cdot \pi$

$\Omega 2 := F2 \cdot 2 \cdot \pi$

$Y(T) := \cos(\Omega 1 \cdot T) + \cos(\Omega 2 \cdot T)$

$$y(T) := 2 \cdot \cos\left[(\Omega 1 + \Omega 2) \cdot \frac{T}{2}\right] \cdot \cos\left[(\Omega 1 - \Omega 2) \cdot \frac{T}{2}\right]$$



The frequencies are obtained from cos(01+02)=0 and cos(Ω1-Ω2) which gives

F1=0.5*(DT2-DT1)/(DT2*DT1)
F2=0.5*(DT2+DT1)/(DT2*DT1)

$DT2 := 0.65$ TIME OF THE HALF CYCLE

$DT1 := \frac{0.041935}{2}$ TIME OF THE HALF CYCLE DIVIDED BY THE NUMBER OF SMALL CYCLES IN IT DIVIDED BY TWO

$$F1 := 0.5 \cdot \frac{DT2 + DT1}{DT2 \cdot DT1} \qquad F2 := 0.5 \cdot \frac{DT2 - DT1}{DT2 \cdot DT1}$$

$F1 = 24.616$

$F2 = 23.077$

$N := 15.5$

$DT := 0.65$

THE FINAL FORMULAS ARE:

$$F1 := \frac{N + 0.5}{DT}$$

$$F2 := \frac{N - 0.5}{DT} \qquad F1 = 24.615 \qquad F2 = 23.077$$

## TABLE 11.7

### SUCTION APPARATUS DRAG, MODEL SCALE

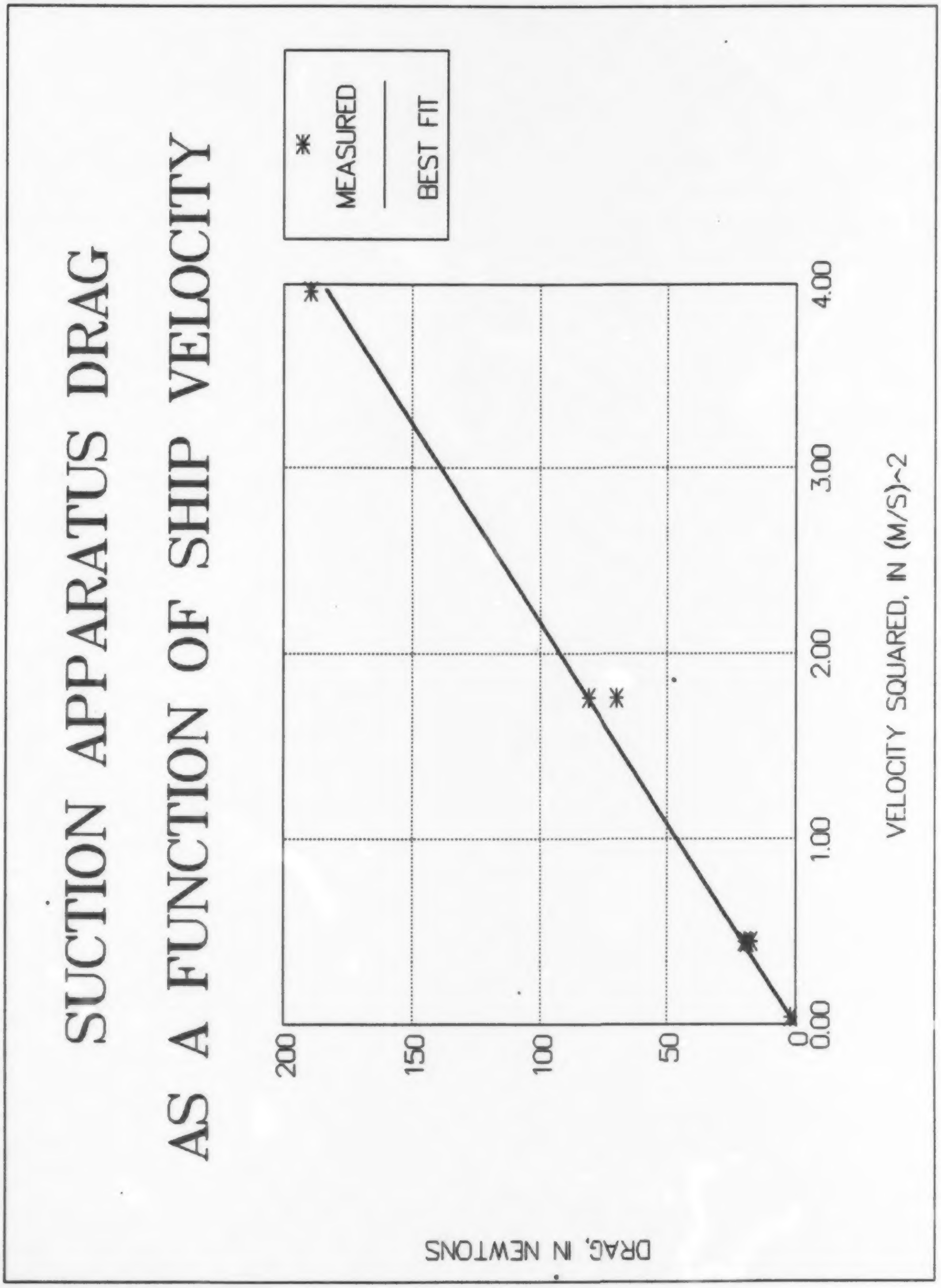
| TEST | SPEED<br>M/S | SPEED^2<br>M/S*M/S | MEASURED<br>N | COMPUTED<br>N | DRAG COEF<br>- |
|---|---|---|---|---|---|
| 0 | 0 | 0.0000 | 0.00 | 0.00 | 0.0000 |
| 31 | 0.663 | 0.4396 | 18.74 | 20.34 | 1.2539 |
| 32 | 0.664 | 0.4409 | 17.22 | 20.40 | 1.1487 |
| 35 | 0.664 | 0.4409 | 19.76 | 20.40 | 1.3182 |
| 33 | 1.328 | 1.7636 | 69.87 | 81.60 | 1.1652 |
| 36 | 1.328 | 1.7636 | 81.33 | 81.60 | 1.3564 |
| 37 | 1.992 | 3.9681 | 189.53 | 183.60 | 1.4048 |

REGRESSION SPEED^2/DRAG

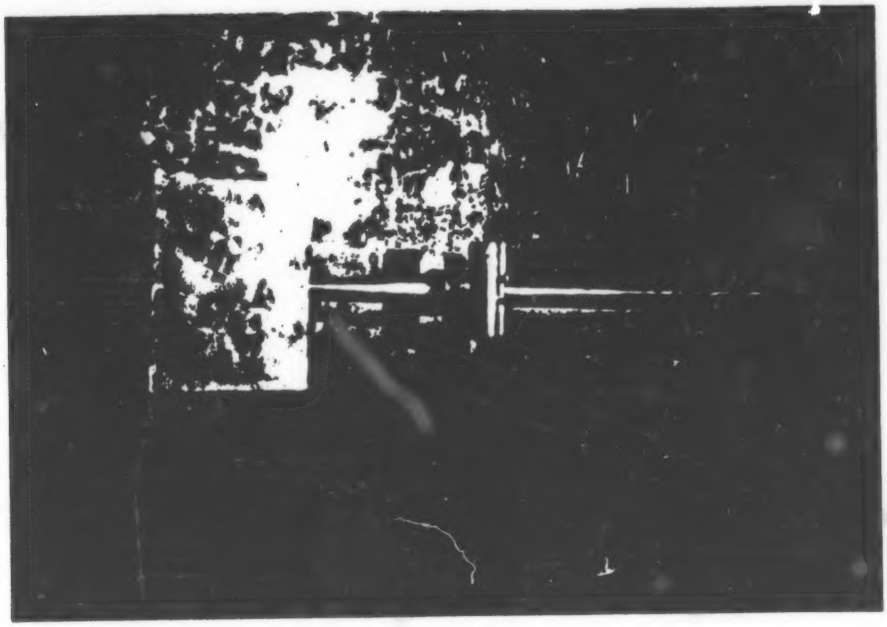
```
         Regression Output:
Constant                              0
Std Err of Y Est                5.56639
R Squared                       0.99285
No. of Observations                   7
Degrees of Freedom                    6

X Coefficient(s)  46.26856
Std Err of Coef.  1.172249
```

ARAD

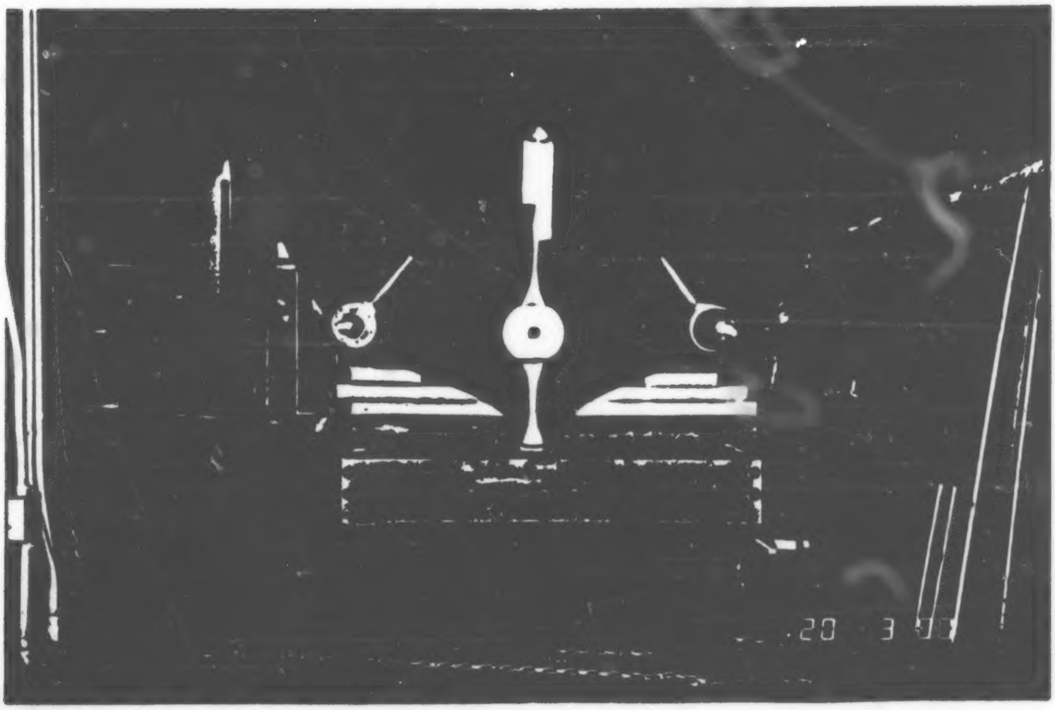
Figure 11.57



SUCTION APPARATUS DRAG AS A FUNCTION OF SHIP VELOCITY



20 3 88


20 3 88

# 12. ANALYTICAL CONSIDERATIONS OF ICE FLOW AND ICE/PROPELLER/NOZZLE INTERACTION

## 12.1. Model/ice interaction - basic analytical considerations

*In terms of ice flow into the propellers, four parameters are fundamental:*

*amount of ice generated by the ship*
*amount of water sucked in by the stern.*
*amount of water going thru propellers*
*distance between the bow and the stern*

*The first three parameters can be described in terms of "sources" and "sinks", in a full analogy to the hydrodynamic sources and sinks. The fourth parameter relates to the geometrical configuration of the sources and sinks, which in turn is related to the dispersion of ice before it reaches the propellers.*

*Below, a brief description of each parameter is given.*

*A ship going thru ice is generating a certain volume of broken ice per unit time:*

$mi$ = *volume of ice generated per unit time.*

*This strength of the source can be expressed as:*

$$mi = B' * H * V \tag{12.1}$$

*where*

$B'$ *is the mean breadth of the channel, in meters,*
$H$ *is the thickness of ice field, in meters, and*
$V$ *is the velocity of the ship, in m/s.*

*The stern area of the ship moving at a velocity V thru water can be represented as a hydrodynamic "sink" absorbing a certain volume of water in a unit time. The strength of this sink can be represented as:*

$$ms = Amid * V \tag{12.2}$$

*where Amid is the midship section area of the vessel. The above formula shows the volume of water being "generated" by the bow (source) and "absorbed" by the stern (sink) per unit time.*

*A propeller sucking in water mixed with ice also can be represented as a "sink". The amount of water going thru the propeller in a unit time can be formulated as:*

$m\ prop = Vprop * S$, *where*

Vprop is the velocity of water in the propeller disk. The fully expanded formula reads:

$$m\ prop = 1/2 * V * S * (1+(1+CT)^{0.5}) \ldots\ldots\ldots\ldots 12.3$$

where CT is the propeller loading coefficient.

Note that the propeller volumetric strength is a combination of a sink and a straight flow thru (when the CT = 0).

The ratios of these coefficients can give us some indication of the ice ingestion into the propeller. For example, if we define

$$ks = mi/ms$$

we can expect that this ratio will give us an indication of the amount of ice being present in the column of water sucked into the stern area.
After substituting for mi and ms, we obtain:

$$ks = c * H/(CM * T) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12.4$$

where:
c is the coefficient expressing the ratio of the channel width to the ship beam (usually near 1),
Cm is the midship section coefficient, and T is the draft of the vessel.

This ratio expresses the simple fact that deep and full ships will have less ice in the water at the stern area than the shallow and fine ships. Note that this ratio is speed independent.

A similar ratio of the amount of ice generated to the volume of water passing thru the propellers can be defined as follows:

$$kp = mi/m\ prop$$

After substitution for mi and mprop, we get the following:

$$kp = 2 * B' * H/S/(1+(1+CT)^{0.5})$$

That is the volume of ice per unit volume of water passing thru the propellers is proportional to the width of the channel, ice thickness and inversely proportional to the propeller load coefficient and propeller disk area. Note that this expression is speed dependent.

The distance between the ice generating source (the bow) and the ice absorbing sink (the propellers) is another important parameter. This is so because of the ice dispersion which takes place between the two. This dispersion is due to the following reasons:

Momentum given to ice by the ship

*Buoyancy of ice.*

*The momentum transferred by the ships bow to the ice blocks results in some ice being pushed away from the hull and surfacing under the ice cover. This motion is counteracted by water which pushes ice back into the wake.*

*Buoyancy forces ice to the surface. As shown in Chapter 6, the time needed to surface a free floating block of ice is depth and size dependent. The time available for the floating up is proportional to the distance between the bow and the stern and inversely proportional to the speed of the vessel:*

$$t = c * L / V \quad \text{.......} 12.5$$

*where*
*c is the proportionality constant,*
*L is the distance between the bow and the propellers, and*
*V is the ship velocity.*

*If we want to establish the ice volume per meter travelled, then the following relationship applies:*

$$\text{Volume of ice per meter travelled} = H * B \quad \text{.......} 12.6$$

*The volume of water entering stern area per meter travelled is:*

$$\text{Volume of water} = CM * B' * T \quad \text{.......} 12.7$$

*The ratio of these two numbers gives us an indication of the amount of ice which could be contained in the volume of water entering the stern area. Numerically it is equal to the ks given by the formula 12.4.*

*In a similar fashion the amount of water going thru the propellers per unit distance travelled can be expressed as:*

$$m\ prop\ (l) = 1/2 * S * (1 + (1 + CT)^{0.5}) \quad \text{.......} 12.8$$

*Note that in this case, the amount of water going thru the propellers becomes infinite at the bollard condition (CT = infinity). The ratio of the amount of ice generated and the amount of water going thru the propellers in a unit distance travelled becomes:*

$$kp\ (l) = kp$$

*where kp is given above.*

*The same reasoning leads to:*

$$ks\ (l) = ks$$

*Thus both of the above ratios are speed independent and they are the same regardless of the unit chosen (unit time or unit distance).*

*If in the expressions for m prop and kp we insert the expression for the propeller efficiency, we obtain the following simple relationships:*

$$m\,prop = V * S / eta \;\ldots\ldots\ldots\; 12.9$$

$$kp = B' * H / S * eta \;\ldots\ldots\ldots\; 12.10$$

*Where eta is the efficiency of the propeller.*

*This expression shows that an efficiently working propeller will ingest more ice than the inefficiently working one. As ice ingestion will lower the instantaneous efficiency of any propeller, the overall efficiency of such a propeller will effectively be lower.*

*The amount of ice which may get into the propellers can be roughly assessed as follows:*

*Volume of ice generated is:*

$$VLgen = B' * H * V$$

*Volume of ice which floats -up before it gets into the propellers is proportional to the amount generated and the time available for floating t:*

$$VLfloat = c * Vgen * t$$

*After substitution for t:*

$$VLfloat = c * L * B' * H$$

*Amount of ice remaining under the surface is:*

$$VLremain = B' * H * V - c * L * B * H$$

*or, in general terms:*

$$\mathbf{VLremain = c1 * V - c2} \;\ldots\ldots\ldots\; 12.11$$

*where c1 and c2 are proportionality constants.*

*This means that:*

1. *The amount of ice in the stern and propeller area should be proportional to the velocity of the ship, and*
2. *There exists a certain onset velocity under which there will be no ice in the stern area and the propellers.*

*In terms of the number of interactions per second, the formula 12.11 can be transformed as follows:*

$NI/per\ sec = (c3 * V - c4) * V$..................12.12

*which again shows the "onset speed".*

***These relationships have been verified by the model tests*** *(see Chapter 13).*

## *12.2. Ice flow around the stern - background*

*In order to understand the flow of ice into or around the propellers, the pressure field generated by the propellers has to be defined and understood. Unfortunately, no data exists in Canada on this subject. Therefore the theory and experimental data is quoted after the Reference 12.1.*

*A propeller working at a certain power level develops the pressure field around it. This field manifests itself by the acceleration of water particles and resulting pressure drop. The closer to the propeller, the higher the pressure drop (suction) is. This suction pressure can be represented by the following formula:*

$delta\ p = ksi * ro * Va^2$..................................12.13

*where Va is the water velocity induced by the propeller. The fully developed expression for the ideal propeller reads:*

$delta\ p = ksi * ro * ((Vp^2 + 2 * T/ro/S)^{0.5} - Vp)^2$.......12.14

*where:*

*ksi is the experimental constant depending on the distance from the propellers,*
*ro is the density of water, in kg/m^3*
*Vp is the advance velocity of the propeller, in m/s*
*S is the propeller disk area,*
*T is the propeller thrust.*

*Figure 12.1 shows the suction pressure delta p as a function of the thrust and advance velocity of the propeller for the ksi coefficient equal to 0.02.*

*The following points are evident:*

- *for bollard condition, suction pressure is proportional to the thrust of the system.*
- *suction pressure drops rapidly with an increase of ship speed. For the speed of advance of 0.5m/s, the pressure drops to less than 1/2 of the bollard pressure.*
- *for the full system thrust of 232.5N the suction pressure is approximately 150N, which is less than the weight of the ice*

*block.*

*For the nozzle propeller/system, the same equations apply, with the disk area being the maximum projected nozzle disk area, and the thrust being the total thrust of the system. The ksi coefficient however must be different (higher)ahead of the nozzle, as the nozzle provides more concentrated (forward directed) pressure field than the open propeller. As no data is available at this time on this issue, we will use the open propeller values for the ksi coefficient.*

*The ksi coefficient depends on the distance from the propeller. Figure 12.2 shows the results of the measurements of the suction coefficient ksi as a function of the axial and vertical distance from the propeller. The following observations are made:*

* *pressure drop is highest just above the propeller,*

* *within two radiae away from the propeller the suction pressure coefficient drops to 10% of its value.*

* *the peak suction pressure coefficient occurs at approximately x/R = 0.5 ahead of the open propeller, not at the propeller disk.*

* *there is a rapid drop of the coefficient with the increase of the distance Y/R*

*An interesting measurement is shown in Figure 12.3, based on the measurements of the pressure field around the wing propellers of the triple screw icebreaker. The following observations can be made:*

* *Pressure drop peaks rapidly at a r/R = 1.5 away from the hull*

* *Inboard turning propeller generates a lower pressure drop than the outboard.*

* *Pressure drop reaches the 10% of its maximum value at r/R = 4*

*If the pressure field above the propeller is integrated spacewise in one plane, we will get the total downward force acting in that plane (under the assumption that the field does not change much with the presence of a rigid boundary, like an ice field).*

*This force is shown in Figure 12.4 as a function of the distance above the shaftline.*
*Important conclusions can be drawn from this figure:*

* *Suction force generated by the propeller on the ice field above it is insignificant in comparison with the propeller thrust. Its maximum is 14% of the propeller thrust.*

* *This force drops off rapidly with the increase of the distance above the propeller. For the distance above the tip of the prop equal to twice the propeller radius, the force drops to 1/4 of its peak value.*

*Table 12.1 shows the results of the computations of the pressure drop delta p using Ignatiev's formulae and the corresponding drop of the water level above the propeller. For a thrust of 250N, the maximum water level drop is 0.016m, which decreases rapidly with an increase of the model speed.*

*For a single ice block floating at a free surface above the propeller, the following inferences can be made:*

* *ice block will behave as the water particles it displaces would.*

* *ice block will not be sucked in by the propeller if the water level does not create the air suction effect.*

*Since the drop of the water level above the propeller is small, the ice will "dip" following the free surface "dip". No other effect will take place.*

### *12.3. Analysis of the hull geometrical properties related to ice flow and ice ingestion into the propellers.*

*A parameter which describes the coverage of the wetted part of the hull with ice "wrapped around" it is the:*

***ratio of the beam to the girth length.***

*The girth length and girth length/beam ratio are shown in Figure 12.5. It is clear, that for most of the ship's length the ratio of girth length to beam is:*

*1.38*

*that is 72% of the bottom's girth can be covered with ice.*

*Another parameter which describes the coverage of underwater hull with ice is the:*

***ratio of waterplane area to the wetted surface.***

*When this ratio is one, all underwater surface is equal to the flat bottom surface and all ice can stay at the bottom. If it is zero, all ice will tend to stay at the sides. For the model, this ratio is:*

*0.70*

*which indicates that 70% of total wetted surface is "flat bottom"* and 30% is a vertical "wall"

Thus these two parameters give a coherent indication of the maximum possible coverage of the underwater hull with ice.

Another indicator of the ice/hull interaction is the length/beam ratio. The larger the ratio, the less ice in the propellers is expected, as it has more time to surface. For this model, the ratio is:

4.54

Another important property of the hull is the angle of inclination of the hull to the ice sheet, calculated as follows:

Denote (see APPENDIX K for details):

angle **alfa** as waterline angle, in degrees,
angle **beta** as frame (flare) angle (to horizontal), in degrees,
angle **gamma** as buttock angle (to horizontal), in degrees.
Then:

the angle of inclination of the hull at any point to the horizontal plane is expressed as:

$$z = \arccos\left(1 + (\tan(alfa))^2 + (\cot(beta))^2\right)^{-0.5} \quad\text{........} 12.15$$

The distribution of this angle along the waterline is shown in Figure 12.6. Note that this angle varies from 30 deg at the stem to 85 at midship.

Appendix K contains the graphs depicting general properties of the hull angles.
The advance velocity of the hull against the flat ice sheet can be represented by the ratio of that velocity to ships velocity.

The total advance velocity ratio can be calculated as follows:

$$Vn/Vs = \left(1 + (\tan(gamma))^2 + (\cot(alfa))^2\right)^{-0.5} \quad\text{...........} 12.16$$

The vertical component of the advance velocity, that is the speed of submergence of a **free ice** piece at a waterline can be calculated as follows:

$$Vv/Vs = Vn/Vs * \cos(z) \quad\text{......................................} 12.17$$

Both relationships are shown in Figure 12.7.

It can be noted that the vertical velocity of submergence at the bow is approximately 40% of the total ship velocity and it falls off quickly to near zero already at station 15.
Also it is interesting to note that the stern has a higher vertical component of the advance velocity than the bow, which indicates that, for the same speed ahead and astern, the ice blocks will be thrown down faster (hence deeper) at the stern than at the bow.

If the **ice piece is restrained** in the horizontal plane, the vertical speed of submergence increases at the expense of the horizontal one. For an ice block connected to the surrounding ice field, this speed can be expressed as follows:

$$Vsub/Vs = Vn/Vs \,/\cos (z) \quad \ldots\ldots\ldots\ldots \quad 12.18$$

This relationship is shown in Figure 12.8.

Important observations can be made from it:

- Velocity of submergence of constrained ice is large at the bow and at the stern, averaging 60% of the ship advance velocity.
- This velocity peaks at frames -0.5 and 15, reaching a ratio of 0.7 and 0.65, respectively.
- This velocity drops off rapidly near the midship.
- The very large vertical velocity component (Vsub/Vs = 0.7) at the stern means that ice is thrown downwards with high speed into the propellers in the astern mode of operation.
- A large downward velocity component also means that the rotating and submerging ice blocks "slap" the advancing hull further increasing its resistance. This phenomenon was first reported by the author of this report in 1982 (reference 1) and was confirmed by the visual observations during this test series.

**The distribution of the ratio Vsub/Vship along the waterline has been confirmed when examining the wax marks on the hull** (see Paragraph 13.14) and the photographs,which show the traces of the wax block corners near the bow (high angles) and near the shoulders (low angles).

These are undesirable properties of the hull form, especially at the stern.

The deadrise of approximately 3 degrees amidship is not sufficient to make ice blocks overcome the friction forces. An angle of 13.5 degrees in needed (see chapter on friction tests). However all other stations have substantial deadrise angles enabling ice blocks to float up before reaching the midship. Figure 12.9 shows the deadrise distribution along the ship. The pronounced peaks at either end of the hull show the presence of the bow ice knife and stern centerline skeg, assuring little ice entering the bottom in ahead or astern mode of operations.

## 12.4 Ice/propeller interaction index

The existing fleet of triple screw icebreakers totals 25 ships worldwide (13 design classes), two of which are canadian.

To assess the relative merits of their designs in terms of ice ingestion, we proceed as follows:

As shown in the preceding paragraphs, the number of ice propeller interactions per second should be proportional to:

ship beam
ice thickness
ship speed

and inversely proportional to

ship length
ship draft

As ice thickness and ship's speed in it is proportional to the power installed, the following simple expression should be considered as an indicator of the frequency of ice/ propeller interaction:

$$IPI\ ind = B * HP / (LOA * T) \qquad 12.19$$

For the triple screw icebreakers the values of this indicator are:

| | |
|---|---|
| Polar Star class | **1313** |
| Sibir class (new) | 1309 |
| Lenin class | 839 |
| **Louis S. St Laurent** | **643** |
| Moskva class | 497 |
| Sibir class (old) | 266 |

For a comparison, the MV Arctic, known for her little ice/propeller interaction in ahead motion has an index of:

106

Figure 12.10 shows the dependence of the ice/propeller interaction indicator as a function of ship displacement.

The first two classes are well known for their ice/propellers interaction problems. This shows that the indicator reflects the correct relationship. Louis S. St Laurent falls below 1/2 of the maximum value and its propellers/ice interactions frequency should therefore be moderate. Two weeks of fact finding mission onboard the ship in 1977 confirmed this conclusion.

## 12.5 Conclusions from the analytical investigations

1. The amount of ice in the stern area (VL remain) should be proportional to the velocity (V) of the ship:

   $$VL\ remain = c1 * V - c2$$

   where c1 and c2 are the proportionality constants.

2. There exists a certain velocity below which there is no ice in the stern and propeller area.

3. Propeller/nozzle suction pressure is proportional to the thrust of the system. This relationship was confirmed during the blockage tests (see Chapter 11).

4. The suction pressure drops rapidly with the increase of the vessel speed. This was also confirmed by the tests.

5. Suction of propeller/nozzle system can not pull the free floating ice blocks down. This would require the air suction from the surface to occur first.

6. The highest drop of pressure is above the propellers.

7. The force exerted by the propellers on the surface ice field is small (less than 14%) in comparison with the system's thrust.

8. Several indicators can be used in order to estimate the amount of ice flow into the propeller area, in the ahead motion. Among them:

   beam / girth length
   waterplane area / wetted surface area
   B * HP / (LOA *T)

where:

B is the ships beam,
LOA is the ship's length overall
T is ship's draft
HP is the power delivered to the propellers

LSSL has a moderate value of this indicator (643), the highest being that for the Polar Star class ship (1313) and the lowest being that for the MV Arctic (106).

9. The velocity of submergence of ice is large (60% of the advance velocity) at the bow and at the stern of the LSSL. This means that ice blocks "slap" the hull when they are being submerged, and that the stern pushes ice blocks down vigorously into the propeller area.

10. Much improvement can be made to the stern design of LSSL.

Figure 12.1

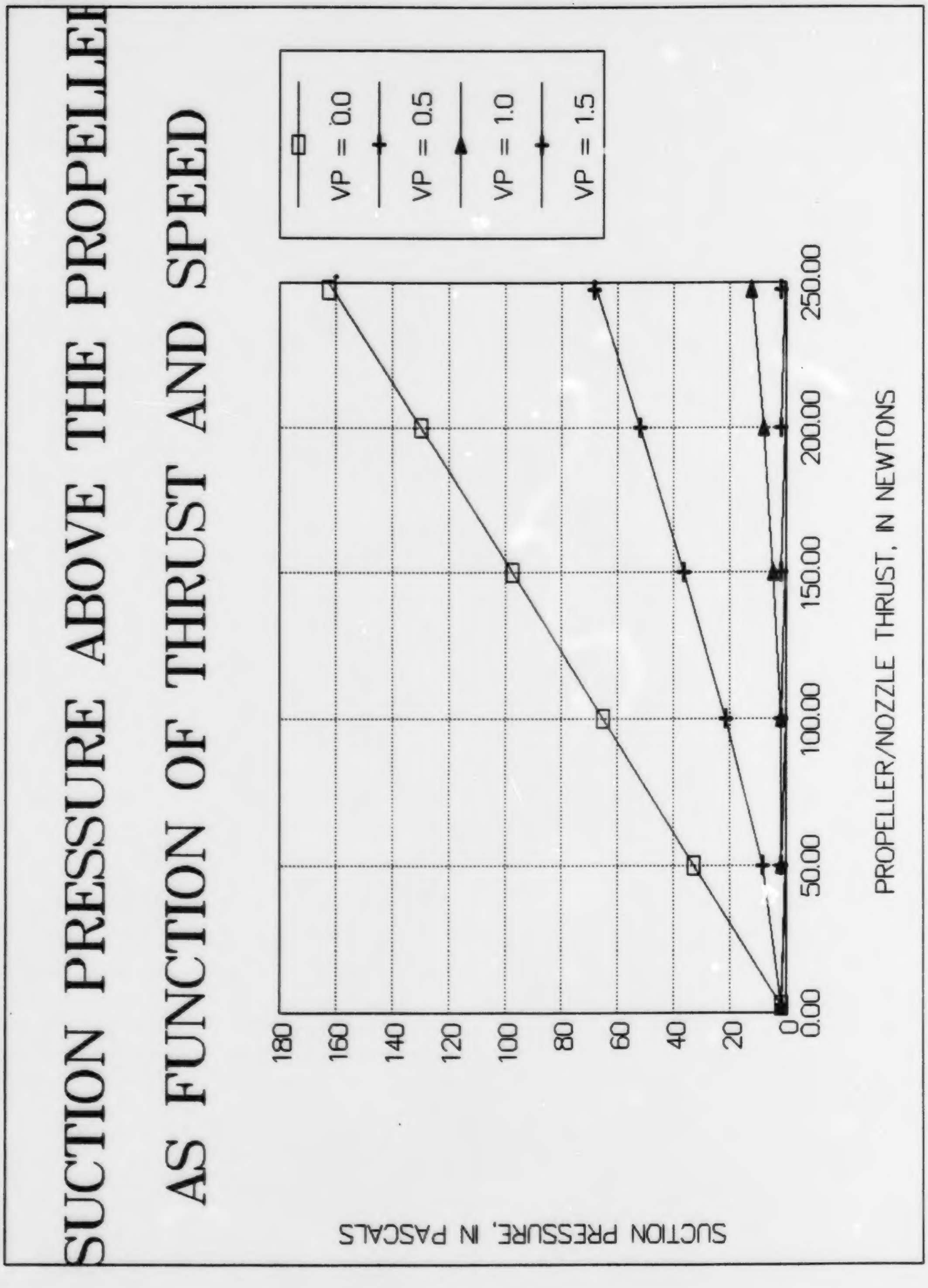
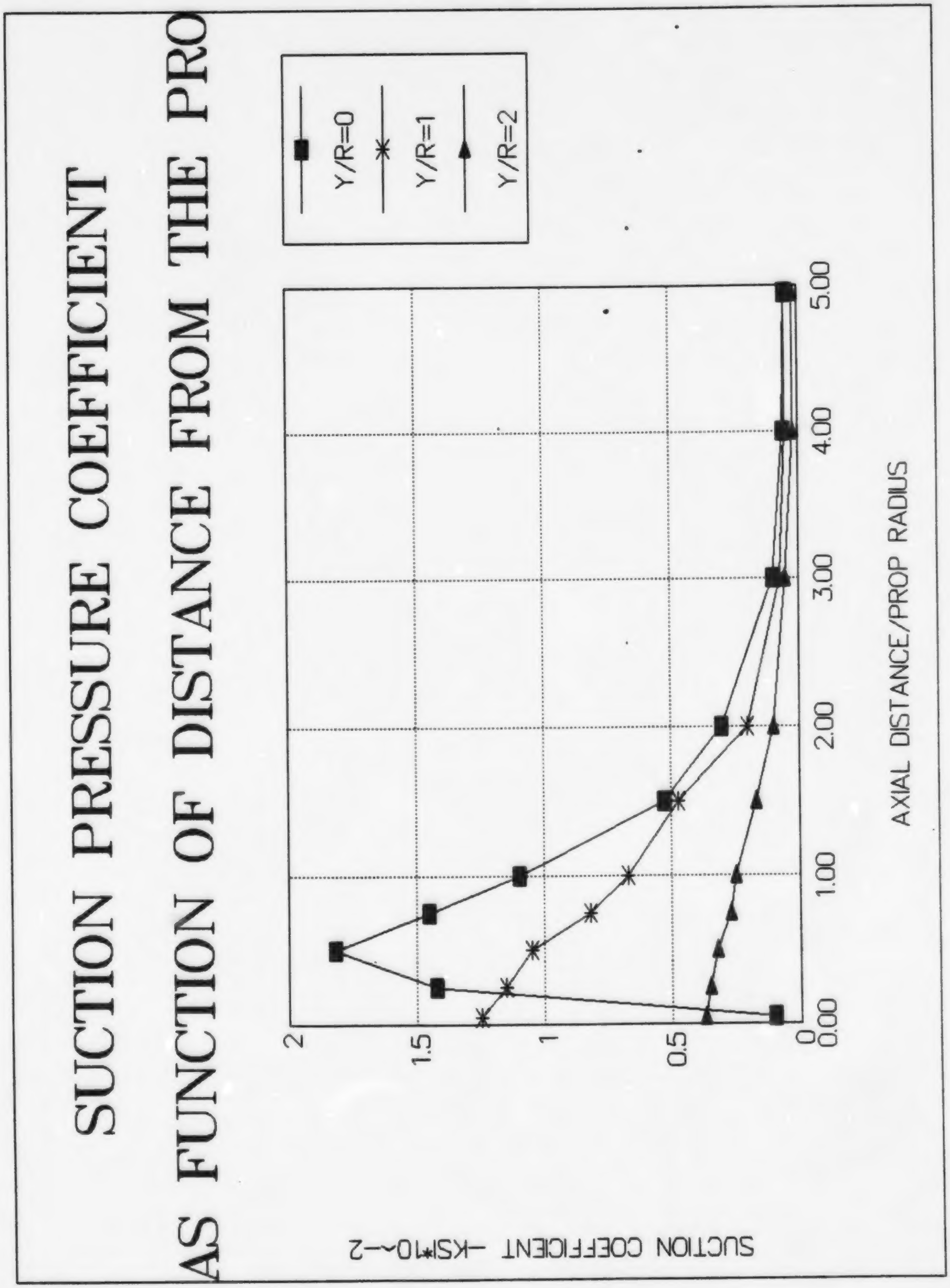

SUCTION PRESSURE ABOVE THE PROPELLER
AS FUNCTION OF THRUST AND SPEED
SUCTION PRESSURE, IN PASCALS
PROPELLER/NOZZLE THRUST, IN NEWTONS
VP = 0.0
VP = 0.5
VP = 1.0
VP = 1.5
0
20
40
60
80
100
120
140
160
180
0.00
50.00
100.00
150.00
200.00
250.00

Figure 12.2



SUCTION PRESSURE COEFFICIENT
AS FUNCTION OF DISTANCE FROM THE PRO

Figure 12.3

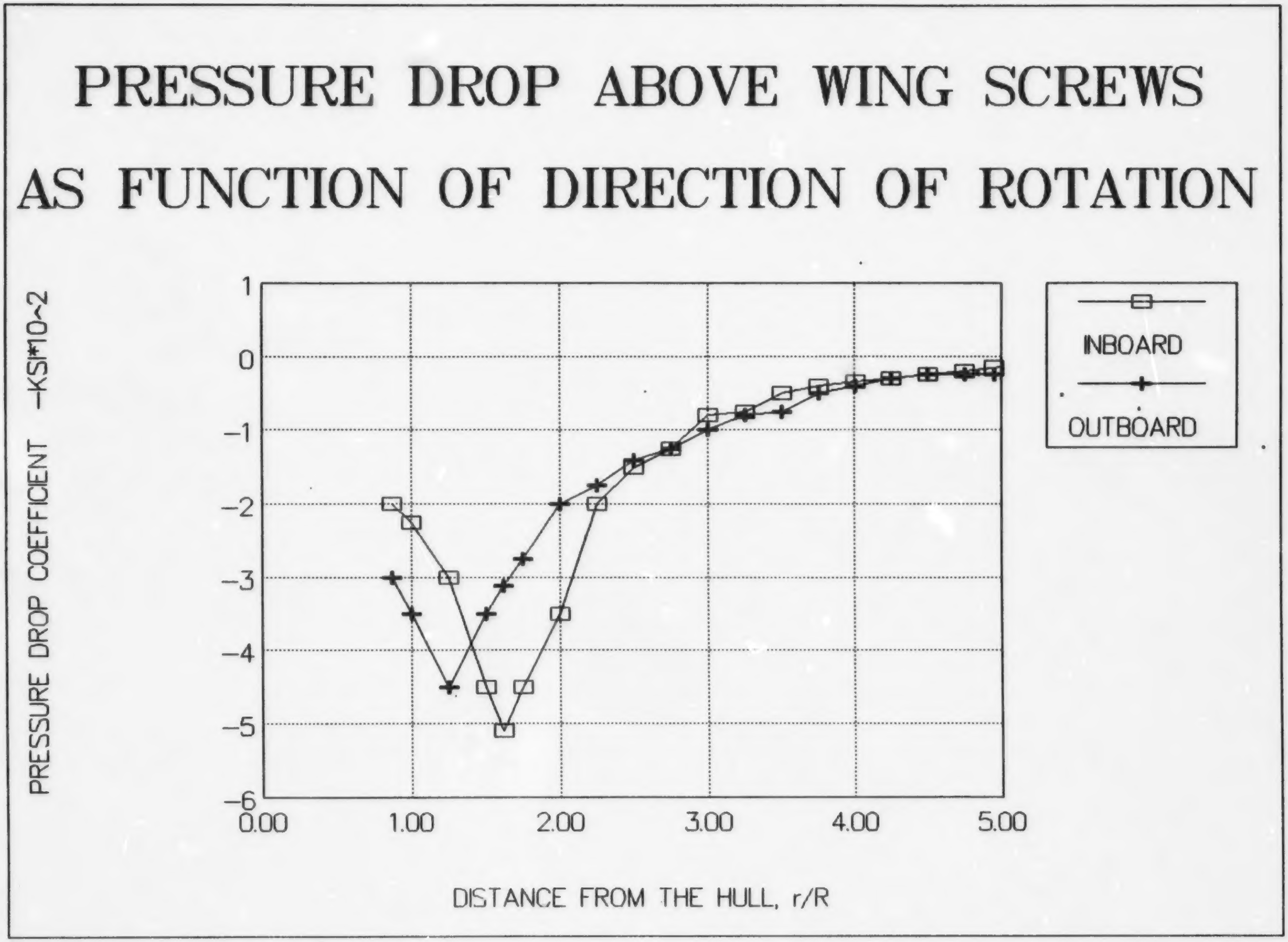

PRESSURE DROP ABOVE WING SCREWS
AS FUNCTION OF DIRECTION OF ROTATION
PRESSURE DROP COEFFICIENT —KSI*10~2
1
0
−1
−2
−3
−4
−5
−6
0.00
1.00
2.00
3.00
4.00
5.00
DISTANCE FROM THE HULL, r/R
INBOARD
OUTBOARD

Figure 12.4

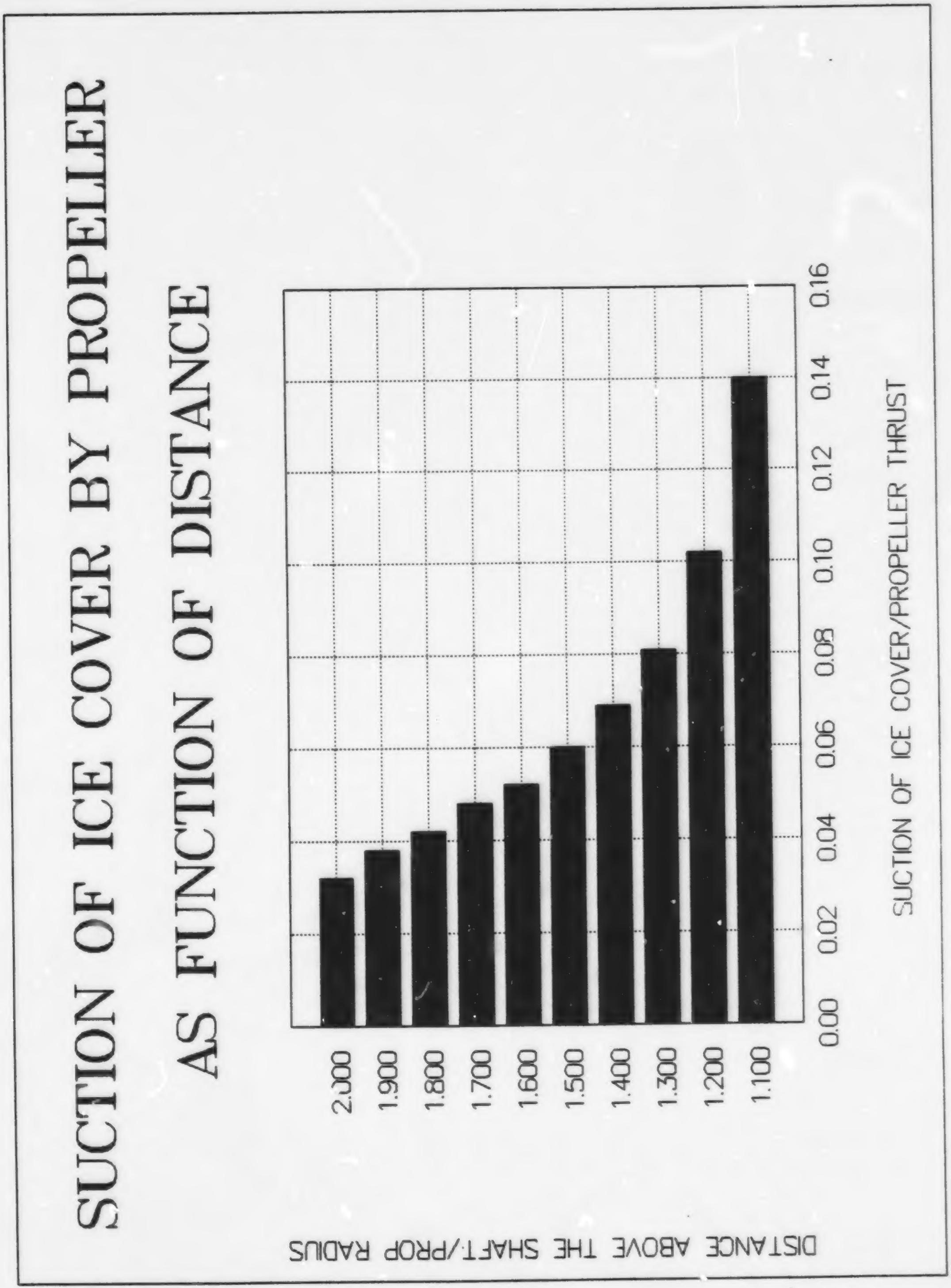
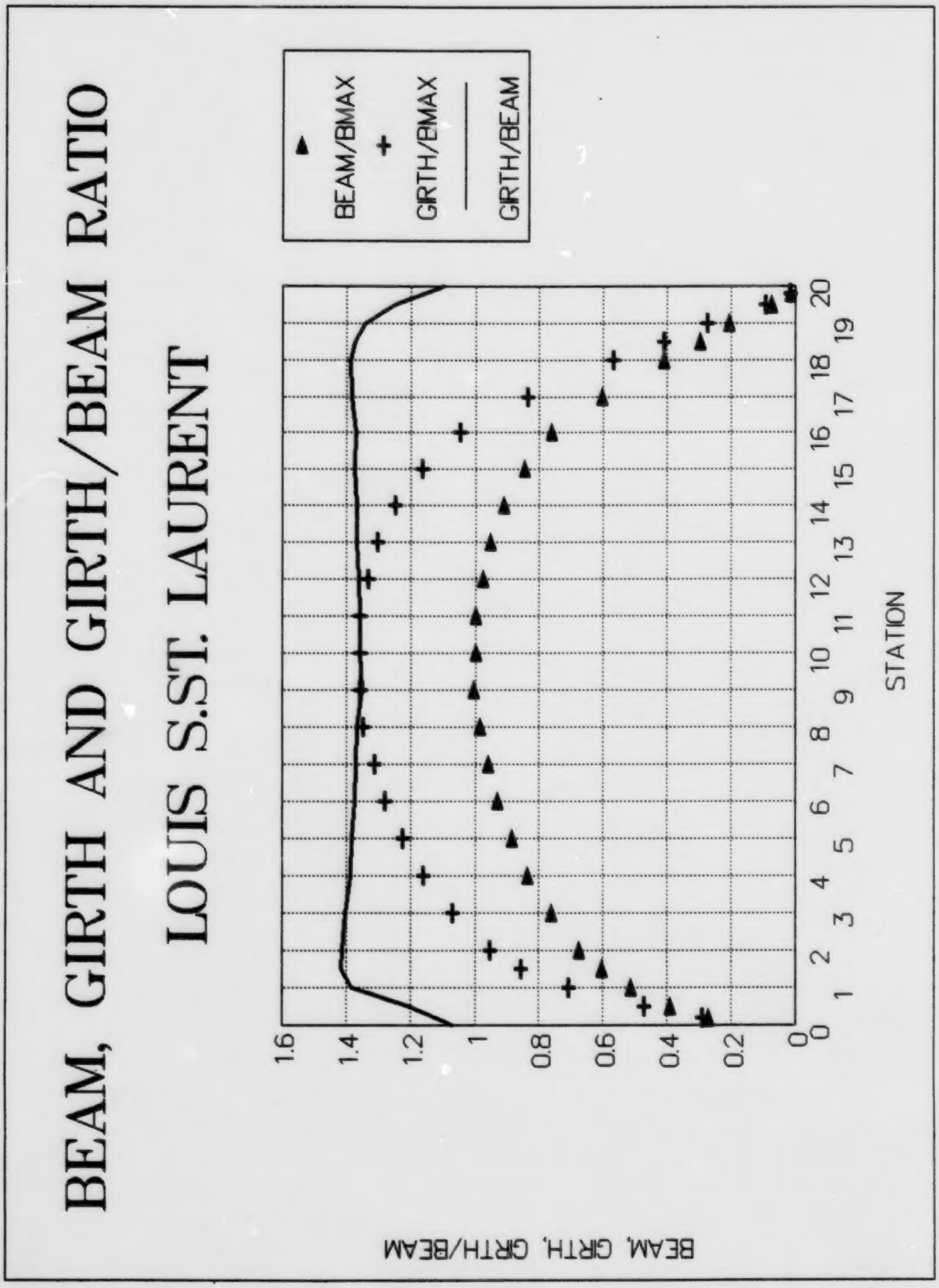

SUCTION OF ICE COVER BY PROPELLER AS FUNCTION OF DISTANCE

Figure 12.5


BEAM, GIRTH AND GIRTH/BEAM RATIO

LOUIS S.ST. LAURENT

Figure 12.6

ANGLE OF INCLINATION OF HULL TO ICE SHEET, 8.7m WATERLINE

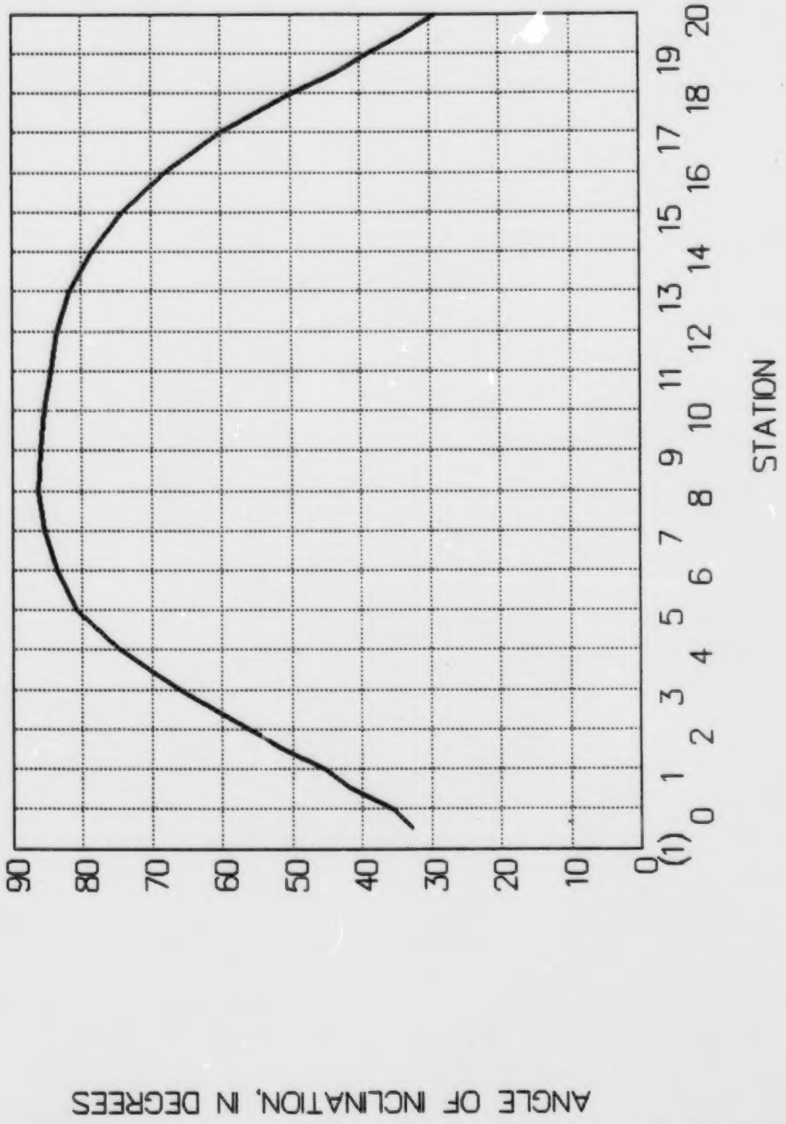


Figure 12.7

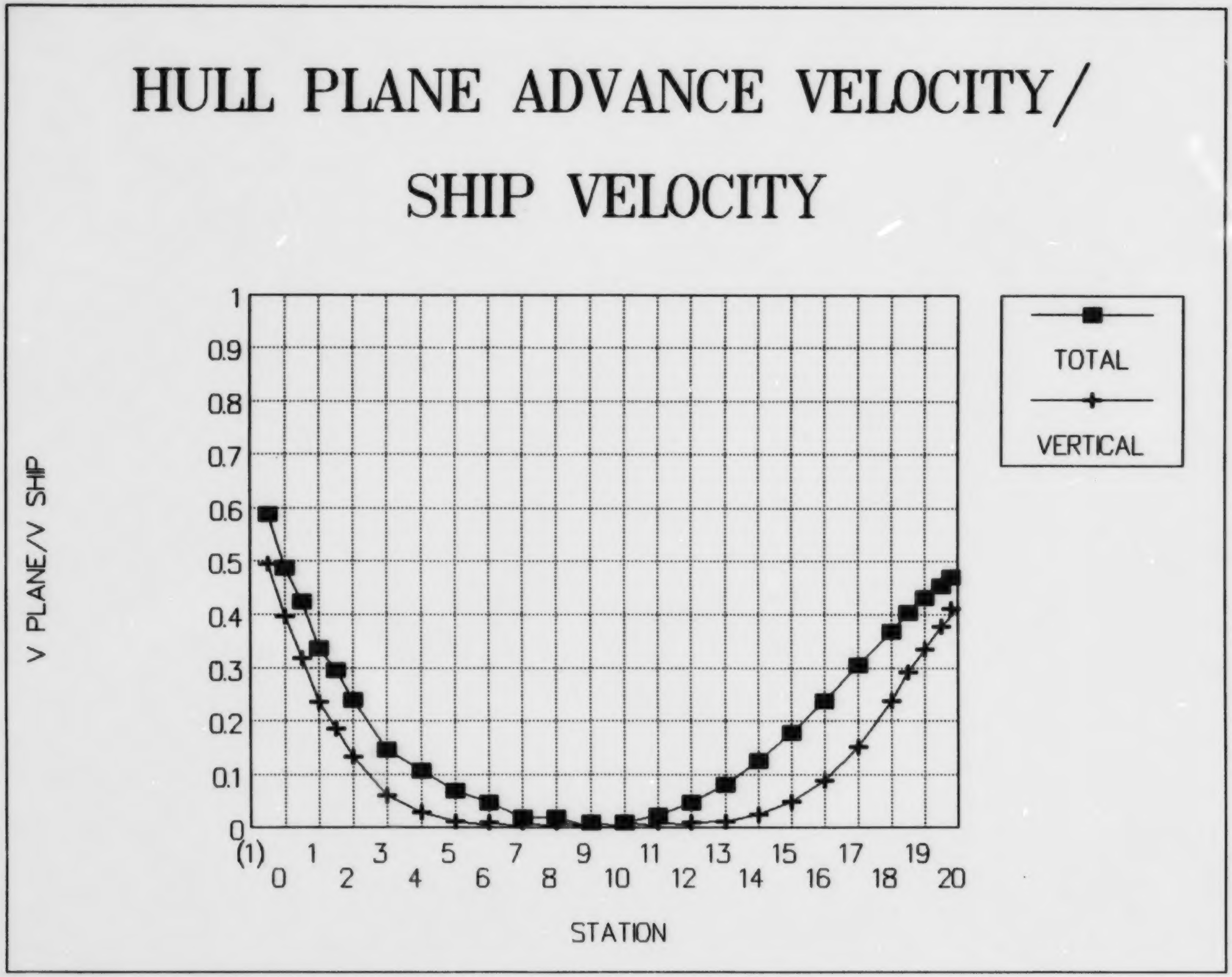

HULL PLANE ADVANCE VELOCITY/
SHIP VELOCITY
V PLANE/V SHIP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
(1)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
STATION
TOTAL
VERTICAL

Figure 12.8

SUBMERGENCE VELOCITY/SHIP VELOCITY

CONSTRAINED ICE

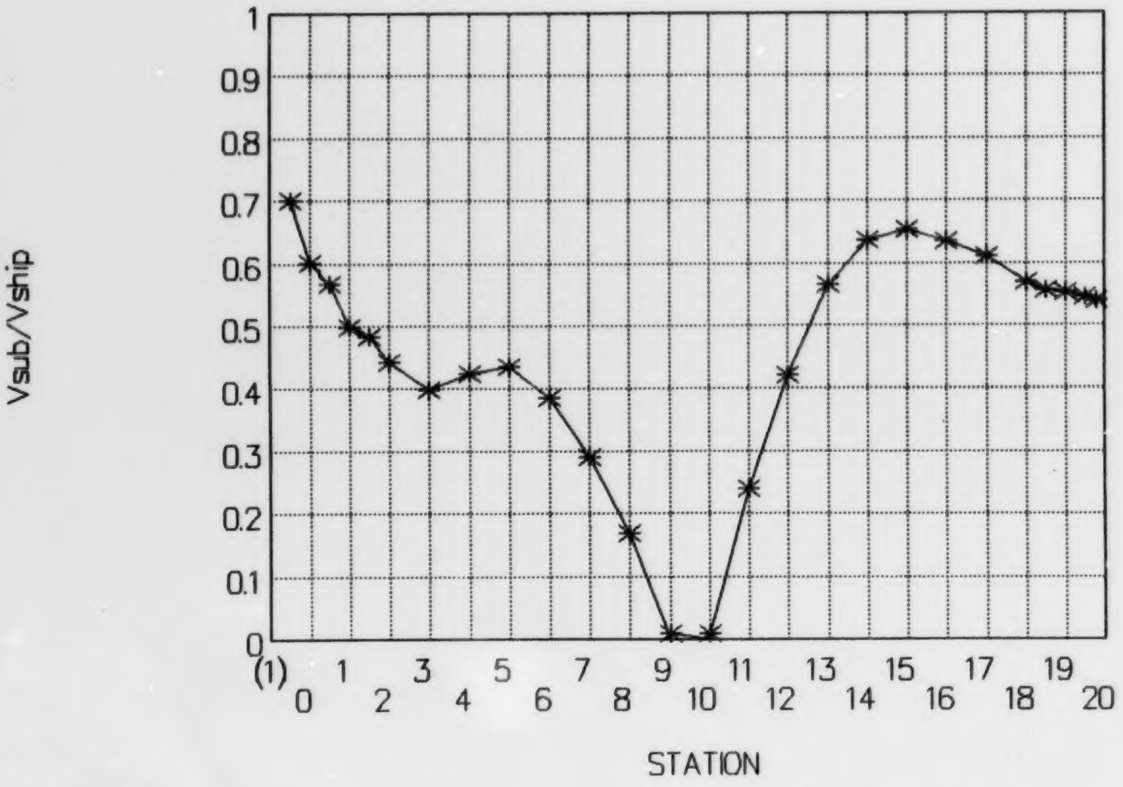
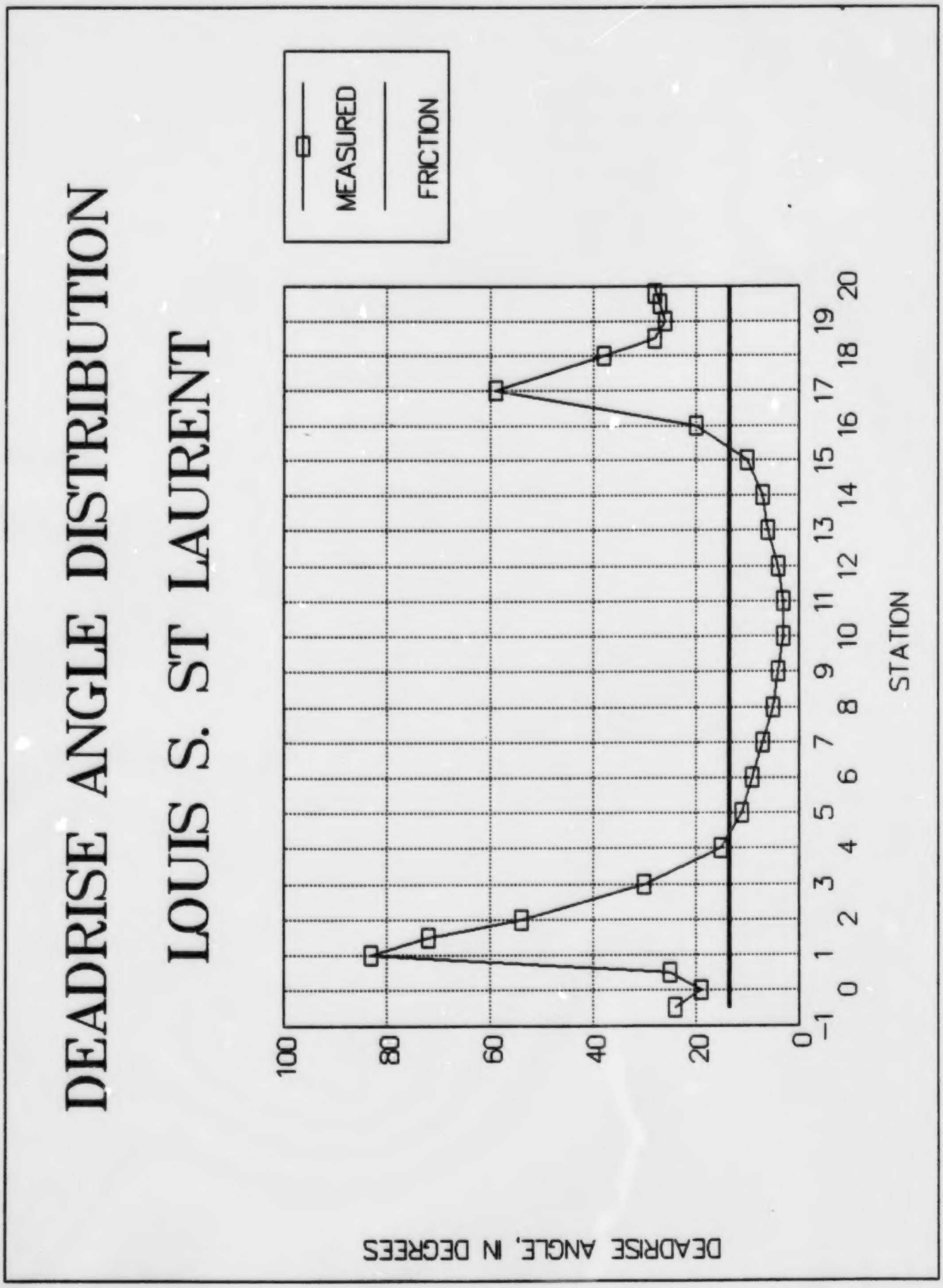


Figure 12.9


DEADRISE ANGLE DISTRIBUTION
LOUIS S. ST LAURENT
MEASURED
FRICTION
DEADRISE ANGLE, IN DEGREES
0
20
40
60
80
100
STATION
−1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

### TABLE 12.1
### CALCULATIONS OF PROPELLER SUCTION POWER USING IGNATIEV'S EXPERIMENTAL DATA

DELTA P = KSI*RO*((VP^2+2*T/RO/S)^0.5 -VP)^2

| | VALUES |
|---|---|
| KSI FROM MODEL DATA | 0.02 |
| T IS THRUST OF PROP | SEE BELOW |
| VP IS THE PROP VELOF ADV | SEE BELOW |
| S IS THE DISK AREA | 0.061575 |
| RO IS WATER DENSITY | 1025 |
| D IS THE PROP DIAMETER | 0.28 |

VALUES OF DELTA P, IN PASCALS

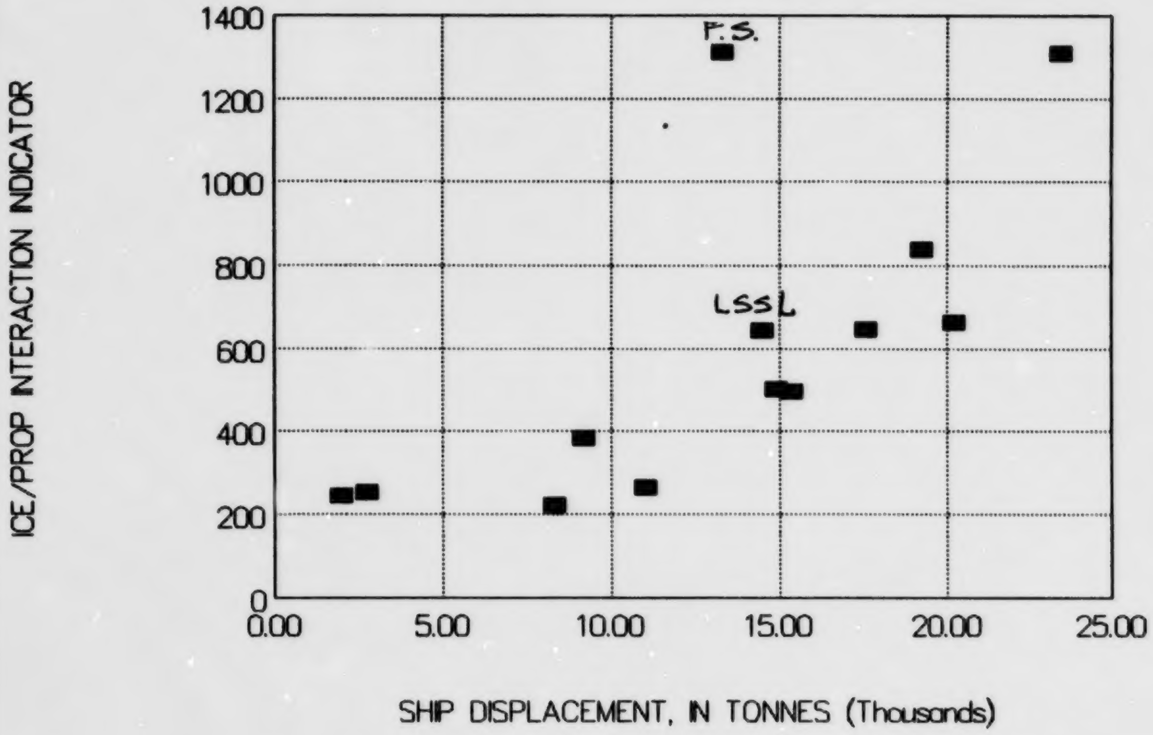
| VP=<br>T | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 |
|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 50 | 32.48 | 8.16 | 0.30 | 0.00 | 0.00 | 0.00 |
| 100 | 64.96 | 21.30 | 1.77 | 0.01 | 0.00 | 0.00 |
| 150 | 97.44 | 36.10 | 4.42 | 0.04 | 0.00 | 0.00 |
| 200 | 129.92 | 51.81 | 8.02 | 0.14 | 0.00 | 0.00 |
| 250 | 162.40 | 68.13 | 12.39 | 0.32 | 0.00 | 0.00 |

VALUES OF DROP OF WATER LEVEL, IN METERS
CORRESPONDING TO THE ABOVE PRESSURE DROPS
DELTA H = DELTA P/1025/9.81

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 50 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 100 | 0.006 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 150 | 0.010 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 |
| 200 | 0.013 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 |
| 250 | 0.016 | 0.007 | 0.001 | 0.000 | 0.000 | 0.000 |

Figure 12.10

## ICE/PROPELLER INTERACTION FREQUENCY INDICATOR FOR TRIPLE SCREW ICEBREAKER



## *13. TESTS IN ICE - SERIES 195 (HULL WITHOUT DEFLECTOR) RESULTS*

### *13.1. Model properties*

**General**

*Model lines are given in Appendix J. Here, we discuss those properties of the model which relate to its interaction with broken ice.*

*Waterline, frame and buttock angles at 8.7 m draft are given in the Figures 13.1,13.2,13.3 respectively. The form of the bow and the stern of the ship is a conventional "vee" shape with low stem angle. The block coefficients of the hull are:*

| | |
|---|---|
| *bow* | *0.520* |
| *stern* | *0.564* |
| *whole* | *0.543* |

*Detailed listing of all the coefficients is contained in Appendix J.*

*Photographs 13.4 to 13.8 show the general hull configuration.*

*The general properties can be summarized as follows:*

*pronounced "vee" shape bow and stern*
*no parallel middle body*
*no flat bottom*
*deadrise of approx 3 deg at midship*
*low block coefficient*
*conventional triple screw stern*

*The nozzle (modified NSMB#37) was fit in the sternframe window. Details of the nozzle, sternframe and the attachments are given in the Appendix L. Design calculations and the optimization of the nozzle/propeller system are contained in Reference 1.*

*Figure 13.9 shows the general configuration of the nozzle in the stern area of the model.*

**Stern**

*The general stern configuration is shown in Figure 13.10.*

*The triple shaft arrangement is of the conventional type, with the wing propellers positionned approx 0.3m ahead of the center one.*
*Detailed drawings of the nozzle, aperture, rudder and bossing are contained in Appendix L.*

From the viewpoint of the ice/propeller interaction the essential numbers are:

Top of the nozzle to the DWL.............0.298m

Centerline shaft to the DWL.............0.552m

Wing propeller tip to DWL...............0.403m

Wing shaft to DWL.......................0.403m

Combined disk area/midship area..........0.28

Combined disk area/(beam*ice thickness)..2.00

The nozzle was mounted on the solid bar equipped with the strain gauges. In order to protect them, a number of short studs were screwed in around the support, **forming a protective palisade.** As the model was not equipped with the ice knife behind the rudder, ice blocks were frequently interacting with this palisade, especially in the going astern mode. Impacts on this palisade were considered as impacts on the nozzle itself.

## 13.2. Ice properties.

Geometry of the corral is shown in Figure 13.11. The length of it was 3.4 times the length of the model, and its width was 2.8 times the beam of the model. These dimensions were sufficient to establish the flow pattern around the hull, since the ice field was composed of regular pieces.
The geometry of the individual ice pieces used to form the ice field were as follows:

## *TABLE 13.1*

### *Geometry of simulated ice field*

| *Individual block size l x b (m)* | *Number of ice pieces in the corral* | | *Total area (m^2)* | *computed coverage (initial)* |
|---|---|---|---|---|
| *0.45 x 0.20* | *375* | | *33.75* | |
| *0.35 x 0.25* | *386* | | *33.77* | |
| *0.30 x 0.30* | *375* | | *33.75* | |
| | | *total* | *101.27* | *.90* |

*measured ice coverage*

| *Test* | *range of coverage* |
|---|---|
| *1* | *0.81 - 0.86* |
| *2* | *0.72 - 0.83* |
| *4* | *0.71 - 0.82* |
| *6* | *0.75 - 0.80* |
| *9* | *0.78 - 0.83* |
| *11* | *0.64 - 0.80* |
| *14* | *0.71 - 0.80* |
| *17* | *0.77 - 0.80* |
| *19* | *0.69 - 0.83* |
| *20* | *0.57 - 0.79* |
| *Average* | *0.76* |

*The discrepancy between the computed and measured coverages are due to the rafting of the blocks.*

*The strength of the ice was determined using the standard testing techniques, details of which are given in the Appendix L. On average, the strength of the wax was found to be:*

*2.1 MPa in uniaxial compression*
*0.1 MPa in bending*

*which is equal to the full scale strength of a weak first year*

*ice. Reduced (scaled down) strength was not possible to achieve with this material and manufacturing constraints.*

*Buoyancy and friction properties of this material were found to be ideal for this testing (see Chapters 6 and 7).*

### *13.3. Summary of the test series 195*

*Table 13.2 lists the tests conducted in ice. All together 20 runs were executed. The variables were:*

*direction of motion: (ahead/astern)*

*ship speed: 1, 3, 5, 10, -0.5, -1.5, knots*

*power level: 100%, 75% of nominal power.*

*direction of rotation of propellers: (inwards/outwards)*

*Ice coverage was nominally 100% and 80% during the tests. See ice properties paragraphs for details of the coverage. Extensive video and photographic documentation was collected during the tests and is reproduced in Appendix L.*

*Recorded signals are contained in Appendix M.*

*Due to the hardness of the model ice, its interaction with the model propellers* ***was more severe than in the full scale.*** *Consequently in order to simulate the interaction more realistically, the propeller stalling interactions were counteracted by reversing the rotation of the propellers, just as it is done in the full scale operations. After clearing the ice from the propellers, normal power and direction of propeller revolutions was restored.*

*A brief descriptions of the selected tests follows (series 195).*

***Test 1.***

*Speed was set at 0.5 knots astern, full scale. Ice was wedging between the rudder post and the hull throughout the tests. Severe interaction with the wing propellers took place. Hull sides were free of ice blocks as the propeller wash was removing them. No ice on the bottom was present. Blockage of the nozzle occurred at the end of the run, lasting for some 10 seconds. A detailed description of the blockage is given at the end of this chapter.*

***Test 2.***

*Speed was 1 knot ahead. Even before the direct contact with hull was made, ice started a slow drift forward. Upon being submerged, immediate breaking up of the "shell" took place. At the bow ice knife ice was already parted and moving up. At the juncture of the two model parts, no ice was present at the bottom, except for the two pieces "glued" to it. A number of pieces showed "bunching" that is sticking together and moving as one set, thru the test. Severe interaction with the wing propellers took place,* *pushing ice blocks vigorously aft. No interaction with the nozzle took place. The gap between the hull and the emerging ice pieces was very apparent (approximately 10mm).*

**Test 3.**

*Speed was 1 knot astern. Large motion of ice field was observed before the direct contact was visible above the camera. Many ice pieces stuck around the rudder and nozzle support. No ice on the bottom.*

**Test 4.**

*Speed was 3 knots ahead. Pronounced forward motion and some pile up before hull appears. Very orderly alignment of ice at the sides of the hull, which is then drawn in to the stern area above the propellers. No ice in the nozzle.*

**Test 5.**

*Speed 1.5 knots astern. Multiple wedging of ice blocks and the bossing. No ice in the channel.*

**Test 6.**

*Speed was 5 knots ahead. Very smooth "plowing" effect at the bow, no pile - ups due to the high pressure of the water against the hull. Much ice is sucked back into the propellers.*

**Test 8.**

*Speed was 0.5 knots astern. All ice was flowing above the propellers.*

**Test 9.**

*Speed 1 knot ahead. May pieces aligned vertically at the sides enter the propeller area.*

**Test 10.**

*Speed 1.5 knots astern. A piece "glued to the bottom" resisted the propeller slipstream wash. Number of ice pieces free floating scrape the hull with their corners.*

**Test 13.**

*Speed 0.5 knots astern. A number of pieces wedged between ice and the propeller bossing above the propellers sliding down on the hull.*

**Test 14.**

*Speed 1 knot ahead. Ice reaches down deep to the bottom of the bow. Submerged pieces at the bow "tumble up" to the waterline. Ice sliding on the bottom moves ahead in a oscillating fashion. Bottom of the hull has some ice coverage. A number of pieces travel with the ship.*

**Test 15.**

*Speed 1.5 knots astern. Many ice pieces at the stern, above the nozzle. Ice clearly is prevented from moving aside by the propeller suction.*

**Test 17.**

*Speed 3 knots ahead. Strong forward motion of ice before interaction with the bow. Some ice passes above the nozzle.*

**Test 18.**

*Speed 1.5 knots astern. A large amount of ice blocks stuck to the bottom travelling with it. Severe interaction with the propellers.*

**Test 19.**

*Speed 3 knots. Pronounced forward motion of ice field. Bow covered with ice down to the ice knife. Ice "tumbles up" the bow. Some pieces travel with the stern, around the propeller area.*

**Test 20.**

*Speed 10 knots ahead. Violent impacting of ice by the bow. Bottom/bilge covered by uncleared ice blocks. Large gap between ice blocks and the bottom. Severe interaction with propellers and the nozzle. First observed blockage.*

## *13.4. Test results - average values*

*Figures 13.12, 13.13, 13.14, 13.15 show the average values of the propulsion forces when operating in the broken ice field. When analyzing these figures, the following points should be born in mind:*

1. *A number of ice/propeller interactions resulted in the rpm reversals (lasting several seconds)in order to clear the ice.*
2. *The points represent the average values within specific windows selected within each run.*

*The following observations are made:*

1. *The center propeller average thrust was less in ice than in the open water. This is evident when the Figure 13.12 is compared with the overload tests Figure 9.4; 9.5 for bollard and 5 knots ahead. The drop is approximately 20%.*

2. *Average nozzle force was less than in the open water conditions. The drop was approximately 10%*

3. *Total propeller and nozzle thrusts were lower in ice than in open water.*

4. *The relationships between the rps and propulsion forces are the same as in open water but give lower values of forces for the same rps or power.*

5. *Large scatter exists when correlating rps, power and the propeller thrust, torque and nozzle forces. This testifies to the transient nature of the interactions and resulting hydrodynamic loads.*

## *13.5 Test results - major interactions*

*Seventeen tests were performed in ice, in ahead and astern modes. Traces of the RPMs of the center and wing shafts were examined for the evidence of major events. An example of one set of the traces with the major events occurring on the starboard shaft is shown in Figure 13.16. It should be emphasized that the wax ice was much stronger than the properly scaled down model ice, therefore many of the propeller/ice interactions resulted in power reversals.*

*Table 13.3 summarizes the results of the inspections of these traces. The intervals chosen for the inspections were those in which the carriage speed and the RPMs of the shafts were stable. A number of major interactions with the shafts were counted and presented in a form of the frequency of interactions*

*per second, and*
*per meter travelled.*

*The following observations and conclusions can be derived from this table:*

1. *All together there were 114 major interactions identified. Out of these, 21 (18%) were in the ahead mode.*
2. *The distribution of the numbers of interactions between the individual shafts was:*

| | |
|---|---|
| *port* | *31* |
| *center* | *37* |
| *stbd* | *46* |

*3. This uneven distribution holds true for the ahead and astern modes counted separately.*
*4. The port shaft saw the least interactions, while the starboard the most.*
*5. The center shaft saw the mean number (approximately) of the wing propellers interactions.*
*6. In the ahead mode of operations, 2.3 major interactions were recorded per test, while in the astern mode 11.6 per test (5 times more).*
*7. The frequency of interactions, per second, of all shafts together was, on the average:*

*0.2/sec in the astern mode, and*
*0.1/sec in the ahead mode*

*8. The frequency of interactions of the center shaft was the average between the wing shaft interaction frequencies.*
*9. The frequency of major interactions per meter travelled was*

*1.14/meter in astern mode, and*
*0.12 in ahead mode of operation,*

*which gives a factor of 10 between the astern and ahead modes.*

*10. In both modes of the operations, the center shaft saw only 90% of the average number of interactions of the wing propellers.*

*Figures 13.17 and 13.18 show the dependence of the total frequency of major interactions (per second and per meter) as a function of ship speed, in ahead and astern modes, respectively. Table 13.4 shows the results of the regression analysis. The following observations are made:*

*1. There is a linear proportionality between the frequency of major interactions NOMI (in both modes of operations) and vessel speed.*

*2. In ahead mode, the relationship is stronger for the NOMI/per seconds, while in the astern mode for the NOMI/ per meter.*

*3. For the NOMI/second there is no interaction observed until the vessel reaches a certain speed in both modes of operations.* ***This confirmed the theoretical investigation contained in the preceding Chapter.***

*4. For the NOMI/meter there is already a number of interactions in the astern bollard condition.*

*5. In the ahead bollard, the NOMI/meter is practically zero.*

*Figures 13.19 and 13.20 show the ratio of NOMI of the centerline shaft to the average of the wing shafts as a function of the speed. No significant influence can be detected in either astern or ahead modes. Therefore we can conclude that the major impact sharing between the shafts is speed independent.*

## *13.6. Test results - number of interactions with the nozzle*

*Bending gauges traces were examined for the purpose of identifying the ice blocks/ nozzle interactions. Those which can be considered as significant were identified and correlated against the ship and propulsion status. An example of the bending moment gauge signal with the interactions identified is given in the Figure 13.21.*
*Figures 13.22 to 13.28 show the correlations of the number of impacts against the nozzle as functions of:*

*mean power of centerline shaft*
*mean RPS value of centerline shaft*
*mean torque*
*mean thrust*

*model draft*
*model speed*

*ice coverage*

*The following conclusions can be made:*

1. *Number of impacts on the nozzle is not correlated with the mean power developed. This is for several reasons:*
    - * *Model speed was constant and power independent.*
    - * *Wing propellers were powered independently from the center one, and they contributed to ice flow into the nozzle*
    - * *In astern mode especially, ice is hitting the nozzle as a result of the stern/ ice field interaction, and not as a result of the suction of ice by the propellers.*
2. *Low average power settings are linked to the large impact forces. Explanation:*

    *When large amounts of ice are fed into the propellers, the frequent reversals are needed to clear the ice. This results in the low average power level. Ice is being thrown down by the stern anyway.*

3. *The same conclusions apply to the RPS/ number of impacts*

*relationships.*

4. *Negative RPS lead to a high number of impacts on the nozzle. These RPS were applicable to the astern mode of operations.*

5. *Above conclusions apply to the torque/number of impacts as well.*

6. *Mean thrust of the centerline shaft is not correlated with the number of impacts. Same conclusions as above apply.*

7. *The maximum number of interactions (9) was recorded at a full draft. This may be because of the limited number of the reduced draft runs.*
   *The reduced draft produced, on the average, more interactions than the full draft.*

8. *Ice coverage, within the range tested, is not correlated with the number of interactions. This is so because within the range tested, the model compacts the surrounding ice field to 10/10 coverage anyway and the number of ice blocks submerged remains independent from the far field coverage.*

9. *Within each coverage, the number of interactions varies widely.*

10. *There appears to be a peak interaction coverage of 0.75 to 0.77. The reason for it is not known.*

## *13.7. Test results - maximum nozzle impact forces*

*Table 13.5 summarizes the largest impact forces on the nozzle and the corresponding model and propulsion status.*

*The largest force recorded was:*

***1,500 N, which is 645% of the system bollard thrust.***

*The direction of this force was astern. The impact occurred when the centerline propeller had not developed any power, and the model was going astern. The draft was 80% of the design draft.*

***All large impacts occurred when the model was going astern.***

*Figures 13.29 to 13.34 show the correlations of the maximum impact forces with the status of the model, ice condition and the status of the centerline shaft. The following observations are made:*

1. *Lighter draft leads to higher forces. The highest force occurred at 80% draft.*

2. *There is no obvious correlation between the maximum impact force and the degree of ice coverage. The peak force was recorded at 7.6/10 coverage.*

3. *Positive impact forces (ahead) were registered at high coverages, while negative impact forces were registered at low coverages.*

4. *The lower the power level, the higher the impact forces are. This may be explained by the same arguments as for the number of interaction/power level correlation (see above). Note that unshrouded propellers develop the highest forces (the ones which break the blades) during the shaft reversals, which are at zero power levels.*

5. *Negative mean nozzle thrust (astern) lead to high impact forces astern. There is no strong correlation between the mean thrust and the maximum impact force level.*

6. *Model speed does not correlate with the maximum impact forces. The majority of the large impacts occurred at negative speed (see discussion above). The highest impact occurred at nearly zero speed.*

### *13.8. Test results - mean, maximum and minimum values.*

*Figures 13.35 and 13.36 show the correlations between the mean, max and min values for the centerline shaft torque and thrust.*

*The following conclusions can be drawn:*

1. *In the ahead condition, the maximum values of the centerline torque are proportional to the mean value.*

2. *In the astern condition, the minimum values are proportional to the mean value of the astern torque.*

3. *Maximum torque did not occur at the maximum of the mean torques.*

4. *The same applies for the minimum torque.*

5. *For the propeller thrust, the ahead maximum values are proportional to the mean values.*

6. *In the astern thrust, there is a weak correlation between the mean and minimum thrust.*

*7. The maximum thrust did not occurred at the maximum of mean thrusts, but at a moderate astern thrust.*

*8. Minimum thrust did not occurred at the minimum of the mean of the astern thrusts.*

*13.9 Analysis of the video tapes with regard to the ice flow and ice/propellers/nozzle interaction can be summarized as follows:*

### *13.9.1 Ice flow under the hull - ahead motion*

*1. Ice blocks are submerged and pushed forward by the bow.*

*2. The depth of the submergence depends on the configuration of the individual blocks, but the deepest submergence observed reached the area of the ice knife (stem bottom).*

*3. There is a water layer between the ice block envelope and the bow surface.*

*4. The blocks tumble and pile up at the sides of the bow.*

*5. The bow pushes ice aside effectively: by station 12 (40% of LBP) there is no ice in the bottom area. Only a few ice blocks were noted at the fore bottom of the ship*

*6. Ice starts emerging already at the bow. About the midship a number of vertically suspended blocks are present near the waterline.*

*7. There was no visible drift of ice blocks far away from the hull.*

*9. As the speed increases, the envelope of ice blocks reaches deeper and clings tighter to the hull. This is due to extra water pressure pushing ice against the hull.*

*10. In the deep draft, most of the blocks are surfaced or near the surface already amidship.*

*11. The passing stern sucks ice blocks in its wake, forcing some thru the disk area.*

*12. Wing propeller/ice block interaction is not frequent at deep drafts.*

*13. Ice blocks seem to enter the propeller disk area as a result of hull/ice interaction, not the propeller suction.*

*14. Ice blocks are kicked aside by the wing propeller blades.*

*15. No blockage was observed during the passage of the hull over the camera.*

*16. Many ice blocks pass just above the wing propeller disks, sliding on the hull.*

*17. Many blocks pass above the nozzle, sliding along the stern frame and bottom of the stern.*

*18. Many ice blocks "bunch" together and move together along the hull.*

*19. Free floating ice blocks often touch the hull with the corners.*

*20. Ice pushed aside and floating vertically at the sides is aligned in parallel to the hull*

*21. Some ice blocks are "glued" to the ship's bottom, moving with it.*

*22. The ice field is in forward motion ahead of the bow. This motion is more pronounced at higher speeds.*

*23. At high speeds, many ice blocks are pushed low down into the turn of the bilge area, and the "envelope" of ice is continuous and intact, as ice does not have time to break up and surface.*

*24. At high speeds, many ice blocks are sucked into the stern area. The motions are violent following water mass movements.*

*Figure 13.37 shows the main features of flow of ice blocks under the hull in ahead mode of operations.*

### 13.9.2 Ice flow under the hull - astern motion.

*1. Most of the ice blocks are pushed under by the stern.*

*2. Little ice, if any, is pushed aside.*

*3. Ice blocks wedge between the hull and the rudder post and between the hull and the nozzle upper surface.*

*4. Ice blocks wedge on the aft part of the bossing skegs, just above the wing propeller disks.*

*5. When the wing propellers operate in astern mode, turning inwards, there is a frequent jamming of ice between the propeller and the hull/skeg.*

6. *Lower draft leads to a massive presence of ice blocks in the propellers/nozzle area.*

7. *There is no ice in the bottom area in astern mode. Most ice is washed away at the wing propellers location.*

8. *At the surface, many ice blocks are" bulldozed" by the stern forming a pile-up moving astern with the ship.*

*Figure 13.38 depicts the principal features of ice flow in astern motion.*

## *13.10. Simulated ice blocks/nozzle interaction*

*From the examination of test records, several types of ice interactions with nozzle were identified. They are:*

*single impacts of nozzle ring*
*interaction with nozzle support/palisade*
*blockage of nozzle intake*
*ice milling inside the nozzle*
*indirect interaction*

*A brief description of each type follows:*

### ***Single impacts***

*An example of such an impact is shown in Figure 13.39 which is a trace of the run #10, at approximately 56 sec into the test. Such an impact is characterized by a sharp peak of the nozzle support gauges (both torsion and bending) of a short duration, without interference with the propeller work.*

### ***Interaction with the nozzle support/palisade***

*An example of this type of interaction is shown in Figure 13.40 (run #6). While large fluctuations of nozzle torsion and bending take place, the thrust and torque remain stable. This type of interaction can last for many seconds, as the ice block may remain caught (wedged) between the nozzle and the hull.*

### ***Blockage of nozzle intake.***

*Runs #1 and #20 show typical blockage events. These are characterized by the pronounced disturbance of the nozzle support gauges as well as the propeller thrust and torque. Initial high impact force and prolonged shaft torque/thrust fluctuations are characteristic of this type of the event, fully comparable to those observed in full scale tests. Detailed description of the blockage is given in the paragraph 13.11.*

**Ice milling inside the nozzle.**

*This scenario was not observed in this series, as the size of the blocks was such that they could not enter deep into the nozzle. See the description of the test series 235 for details.*

**Indirect interaction**

*Run #13 gives a good example of such an interaction, where both wing propellers were reversed as a result of their heavy interaction with the blocks.*
*All nozzle gauges and the centerline shaft torque and thrust responded to those changes. This type of interference is characteristic of the triple screw arrangements where the slipstreams are spaced closely together.*

### *13.11 Blocking of nozzle with ice blocks*

*Out of the twenty tests, only two cases of blockage were clearly identified:*

*at the end of run # 1 (astern operations), and*
*at the end of run # 20 (ahead operations).*

*The run #1 is very characteristic of this type of interaction. The following observation are made after examining the traces:*

*Before the actual contact ice/nozzle occurs, the changes in the hydrodynamic flow result in the change of the nozzle torsion and bending moments. These changes are quite pronounced and amount to the 30% of the maximum torsional moments. This phase can be called a **shadowing**, in an analogy to the full scale phenomena observed. The most pronounced shadowing occurs for the nozzle, but the propeller thrust and torque are also affected (increased).*

*A series of short **hard impacts** follows, before the block finds an equilibrium position on the nozzle. It should be noted that the torsion gauges hard impacts were not in phase with the bending moment peaks. These two modes of response are not fully coupled.*

*At that point, the **blocking phase** begins, characterized by the rapid fluctuations of the center shaft RPS (a drop is registered), torque (increase) and thrust (change of sign and increase).*

*These symptoms of blockage are fully compatible with the behavior observed in the full scale trials and the controlled blockage experiments conducted during this project (see Chapter 11).*

## *13.12. Ice flow around the hull - visual observations at the surface*

*A ship entering a broken ice field creates a pressure field in it. This pressurization is achieved by means of the following elements:*

- *direct contact forces between hull and ice,*
- *submerged ice pushing on the surface ice field*
- *hull water drag forces on ice,*
- *propeller induced water pressure forces.*

*The direct contact forces acting on the ice field are:*

*normal forces due to contact pressure, and*
*tangential forces due to the ice/hull friction.*

*These forces are depicted schematically in Figure 13.41.*

*The submerged ice pieces also interact with the surface ice sheet by pushing it to the side, especially at the bow area.*

*As the ship moves thru the broken ice field with a certain speed, it pushes water mass forward. This motion creates drag on the ice field forcing it to move with the water.*

*Propellers induce the water mass to move aft, in a direction opposite to that induced by the drag forces. This motion induces the ice field to move with it.*

*Thus the physical processes leading to the* ***pressure buildup*** *in the surface ice cover are:*

*direct contact hull/ice*

*submerged pieces pushing on the free floating ones*

*hull water drag*

*The processes leading to the* ***pressure relief*** *in the surface ice cover are:*

*submergence of ice blocks by the bow*

*propeller induced velocity field "washing" ice*

*downstream*

*Figures 13.42 and 13.43 show the schematic distribution of the*

*ice block velocities at the surface.*
*Figures 13.44 and 13.45 show the influence of the propeller wake on the ice covearge in the ahead and astern bollard conditions, respectively.*

*The motions of individual blocks observed on the surface are:*

- *submergence*
- *emergence*
- *rafting*
- *rotation*
- *sliding*
- *colliding*
- *drifting*

*A brief description of each motion type follows*

**Submergence.**

*Hull inclination causes ice blocks to submerge. The speed of submergence is governed by the downward velocity component, as defined in the preceding paragraphs. Observations of the behavior of ice pieces have shown that the submergence is an orderly process near the stem of the model, and becomes more erratic near the shoulders. This due to the increased velocity component there and the disruptive influence of the friction.*

**Emergence.**

*Submerged ice pieces form the underwater "shell" pressing upwards against the hull and surface ice. If the hull has large curvature, the shell becomes quickly unstable, breaks up and individual ice pieces float to the surface. They emerge in the gap between the hull and undisturbed ice field or they stay submerged under the ice cover at some distance from the hull, forming now rafted ice field.*

**Rafting**

*If the ice cover is 10/10, then the only place for displaced ice pieces is the underneath of the undisturbed ice cover. Near the model, many different layers of rafted ice were apparent; away from it only few pieces were found. Lower the ice coverage, lesser degree of the rafting was observed, as ice filled in the available voids.*

*The rafting was very pronounced when going astern, due to the restraining action of the rudder and nozzle foundation. Also, the propellers created the suction field keeping the ice near the hull, not allowing it to disperse.*

**Rotation**

*Rotation of ice blocks is the "easiest" motion in terms of the energy required to initiate it and to sustain it. All pieces showed some degree of in-plane rotation in addition to the vertical rotation when being submerged.*

### *Sliding*

*Sliding edge-wise and face on face was very pronounced. It is believed that when the contact takes place there is always a thin layer of water present between the two surfaces, which prevents the direct contact and lubricates the ice pieces.*

### *Colliding*

*Ice blocks used were very rigid and consequently when interacting with each other developed small areas of high pressure against the hull and other pieces. After each test, a number of small particles and crushed and sheared pieces were always found, even when the ice/propeller interaction was absent.*

### *Drifting*

*Two zones of drifting were observed:*

*outside the slipstream, and*

*in the slipstream.*

*Outside of the slipstream, the single ice pieces were following the streamlines filling in the stern void and the channel. When some pieces were caught by the slipstream, rapid acceleration of those resulted and the pieces were washed away for the large distances. A general drifting forward was observed of the loose ice pieces, except in the slipstream.*

## *13.13 Simulated ice block damages by the wing propellers*

*Photos 13.46 to 13.54 show the footprints of wing propellers in simulated ice blocks.*

*The following observations are made:*

*1. There are two basic types of interaction:*

- *transient type, where the ice block is kicked away by the propeller (photos 13.46, 13.49, 13.53), and*
- *steady type, where the ice block "sits" on the hub*

*and the propeller for a prolonged period of time (photos 13.47, 13,48, 13.50, 13.51, 13.54).*

2. *The transient type is characteristic of the ahead mode of operations (see video tapes). The bossing in front of the propeller prevents ice blocks from reaching the center of the propeller, hence the blocks can not achieve a stable position during an interaction. Edges of the blocks and shallow surface grooves are milled out*

3. *In astern operations, the block is sucked into the propeller disk area and can position itself against the hub cup, the blades and the stern, achieving an equilibrium position. Holes present in the blocks testify to this configuration. Deep grooves are milled out in this scenario. Reversing the propellers to the ahead pitch ends the process.*

4. *All of the milled blocks recovered show the surface grooves spaced at different intervals, which means that the block or the propeller was decelerating/accelerating during the interaction.*

5. *The angle of sweep is:*

   *for the transient type, approximately 10 degrees.*
   *for the steady type, approximately 45 to 60 degrees.*

6. *The depth of the cut is:*

   *for the transient type, approximately 5 mm*
   *for the steady type, approximately 30 mm*

7. *Videos show that the milling of ice blocks results in many small "chips" being removed from the blocks of the approximate size 0.03 X 0.03 m.*

*Although the mechanical properties of the blocks are different from the properties of the arctic ice, the basic interaction scenarios and the observations listed above are thought to be valid in full scale as well.*

### ***13.14. Traces of ice blocks on the hull***

*Photographs 13.55 to 13.56 show typical traces of wax on the bow and stern parts of the model. They were made by the corners of the rectangular blocks fretting against the hull.*

*The following observations are made:*

***Bow***

** Near the waterline, the traces follow the buttock lines near* the stem, and then become more horizontal near the shoulders.

This proves that the individual blocks are being submerged where the frame angles are small, and being pushed aside in a horizontal plane where the sides are becoming vertical.

* There is the heaviest concentration of crushed wax marks right above the ice knife (station 17), showing the high pressure zone.

* The zone of the heaviest marks extends from the stem to station 16 and vertically from 1.2 to 0.6 of the design draft.

* No marks are noticed at the ice knife.

**Stern**

* Heaviest concentration of wax markings is at the stations between 0 and 1/2, and between the 100% and 80% of the draft.

* No directional preference can be established for that zone.

* Lower half of the nozzle shows a number of crushed wax marks, testifying that many ice impacts took place there.

* At the very aft end of the stern, the wax marks lie both horizontal and buttock-wise.

* Upper rudder edge, rudder stock, propeller bossings show very strong wax marks.

* The centerline bossing shows the marks from down up into the nozzle area

* Even the bottom of the rudder has some wax marks.

* Wing propeller bossing skegs show heavy sliding marks along the bossings.

* Stern area has much more extensive wax markings  than the bow.

* Wax is an excellent material for its "tracing" capability.

## 13.15 Conclusions from this test series

The main conclusions from the test series are listed below.

PERFORMANCE OF THE NOZZLE/PROPELLER SYSTEM

1. The performance of the centerline propeller and nozzle, as well that of the wing propellers was inferior when compared to the performance in ice free waters. One reason for it was a necessity to reverse the RPS when a heavy block/propeller interaction occurred.

MAJOR INTERACTIONS

2. The port shaft saw least major interactions, the starboard shaft the most, and the center shaft the average between the two.

3. Ahead mode of operations saw 10 times less interactions per meter travelled than the astern mode.

4. The frequency of major interactions is proportional to ship speed, in both ahead and astern modes of operations.

5. In both modes of operations, there is a certain minimum speed, below which no interactions take place between the propellers and ice. The number of interactions per second can be expressed as:

$$NOMI = A + B * V \quad \text{..........................} 13.1$$

   where A and B are constants and V is the ship speed.

IMPACTS ON THE NOZZLE

6. Major impacts sharing between the shafts is speed independent.

7. The number of impacts on the nozzle is power independent.

8. The reversed RPS lead to the high number of impacts of the nozzle

9. The reduced draft resulted in the increase of the number of interactions.

10. Within the range tested, ice coverage is not correlated with the number of interactions.

IMPACT FORCES

11. The largest impact force on the nozzle was 645% of the system's bollard thrust. It occurred in the astern mode of operation, at a reduced draft.

*12. All large magnitude impacts occurred when ship was going astern.*

*13. Lighter draft of the vessel leads to the higher magnitude forces.*

*14. There is no clear correlation between the magnitude of the impact forces and ice coverage.*

*15. High impact forces are linked with the low average power levels.*

*16. There is no strong correlation between the mean thrust and the maximum impact force level.*

*17. Above considerations lead to the conclusions that the frequency and magnitude of interaction forces are geometrically related, that is they depend on the hull and shaft configurations and the proximity of the ice field, not on the suction ability of the propulsors.*

*18. Low speeds generate highest impact forces.*

### *STATISTICS OF THE SHAFT TORQUE AND THRUST*

*19. The maximum and minimum values of the torques recorded were proportional to the mean values developed during the runs.*

*20. The same applies to the thrust, except in the astern mode, where there is a weak correlation between the maximum and mean values.*

### *ICE FLOW*

#### *Ahead motion*

*21. The bow clears the ice pieces effectively. At station 12 there is no ice in the bottom region.*

*22. The deepest submergence of the blocks reaches the region of the ice knife.*

*23. Emergence of ice blocks is linked to the tumbling of the ice block envelope surrounding the hull.*

*24. At a deep draft, there is little wing propeller/ice block interaction, as most of ice pieces pass over the propellers.*

*25. The ice pieces are sucked in by the stern, rather than the propellers, and they come from the sides of the ship not the bottom.*

*Astern motion*

*26. In this mode of operation, ice is pushed down into the propellers by the stern.*

*27. Ice blocks wedge between the hull and rudder post, hull and nozzle upper surface and hull and wing bossing skegs.*

*28. The wedging of the blocks on the wing propeller bossings is very pronounced and leads to the creation of frequent pile-ups in the stern area and severe ice/propeller interactions. This wedging is partially due to the inward turning propellers (in this mode of operation).*

*29. Wing propellers rotate inward in the astern mode of operations pushing ice downward along the hull. Outward rotation would result in less interactions and lower forces.*

*30. Lower draft leads to the massive presence of ice blocks in the stern/propeller area.*

*31. The stern of the ship piles up the free floating ice blocks and pushes those in front of it.*

*NOZZLE/ICE BLOCKS INTERACTIONS*

*32. The following are the modes of interactions recorded during the tests:*

*single impacts*
*interactions with the nozzle support*
*blockages*
*milling*
*indirect interaction*

*Indirect interactions are the result of the wing propellers reversals due to the milling of ice blocks which results in a significant disturbance of the hydrodynamic condition of the nozzle/propeller system*

*33. Only two cases of blockage of the nozzle were recorded during this test series:*

*one in the astern operations, and*
*one at the reduced draft ahead, speed 10 knots.*

*This very limited amount of the blockage is due to:*

*good ice clearing capability of the bow*
*wing propellers and their wash providing an effective force against ice blocks moving around the nozzle*
*deep draft of the vessel.*

## *ICE BLOCKS/HULL INTERACTION*

*34. The hull of the vessel moving in a broken ice field compresses and moves the blocks ahead of itself creating an artificial high density zone in the bow or stern area.*

*35. Ice blocks are submerged when the frame angles (measured to horizontal) are small, and are pushed aside when the frame angles are large.*

*36. There is a high pressure area on the bow right above the ice knife (station 17)> This area extends from the stem to station 16 and from the above waterline to the 60% of the vessel draft.*

*37. All appendages at the stern show large number of heavy interactions with the blocks.*

*38. Bottom of the nozzle shows the evidence of interactions with the blocks. So does the bottom of the rudder.*
*This is most likely due to the fact that the wings propellers kick ice blocks down below the keel when operating in the astern mode.*

*39. Wing propeller bossing skegs show pronounced marks of ice blocks sliding along.*

*40. Stern area shows the traces of much more heavy interactions with blocks than the bow area.*

Figure 13.1

LOUIS S. ST. LAURENT

WATERLINE 8.7M

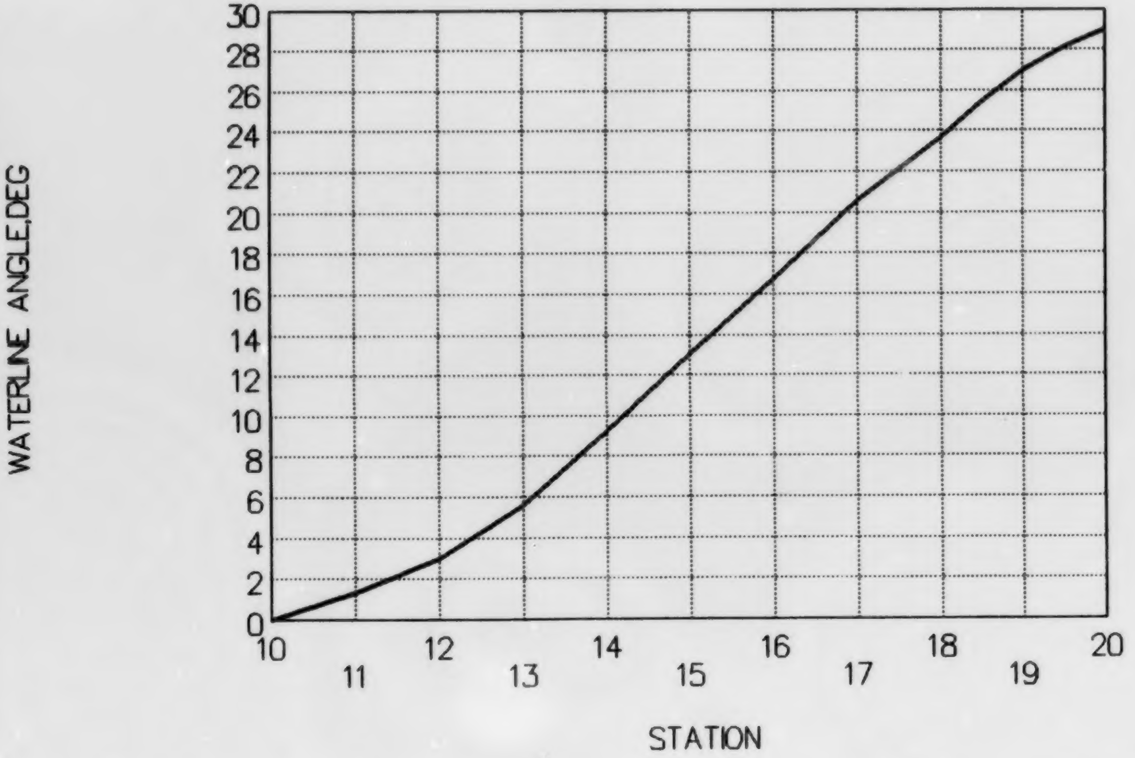


Figure 13.2

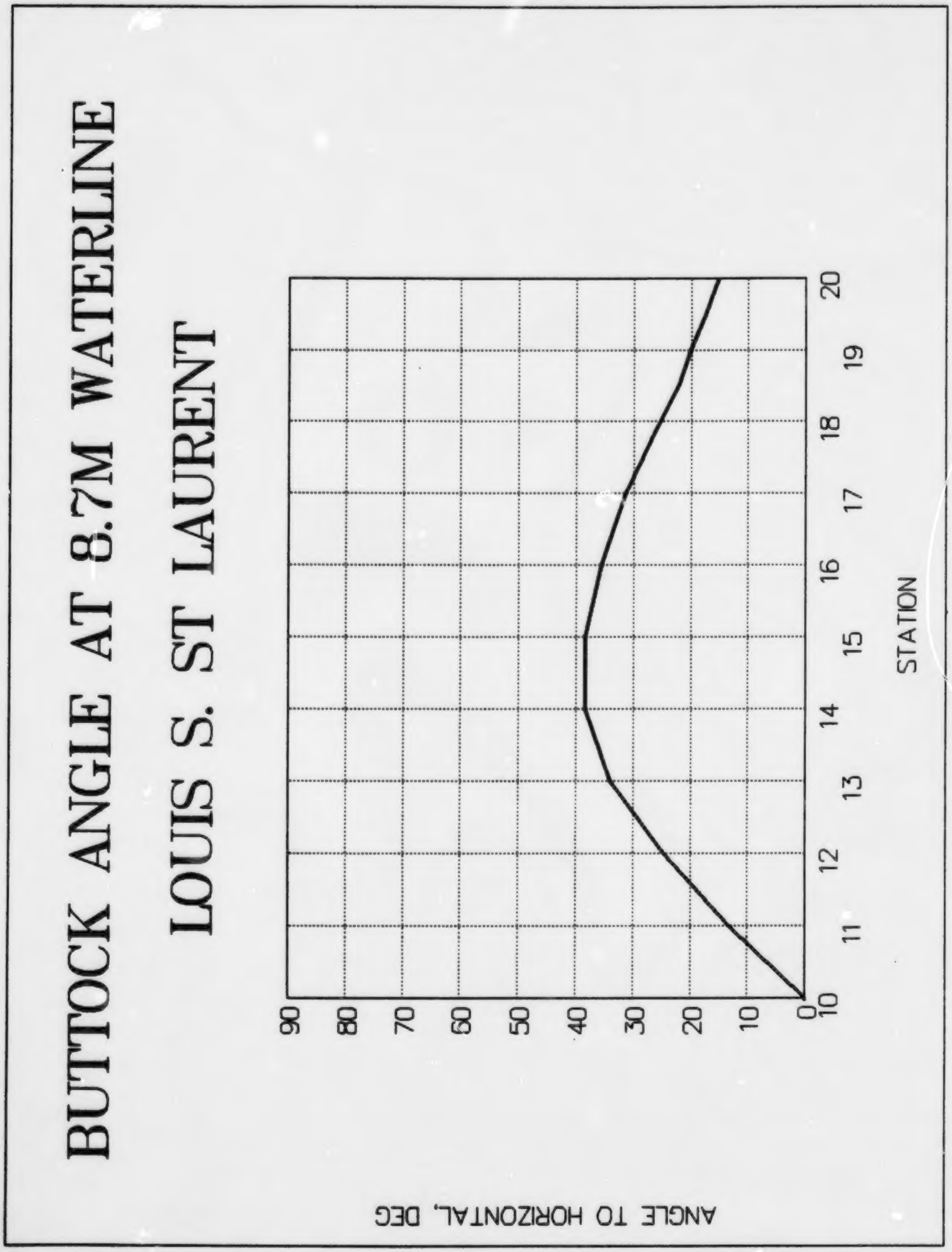
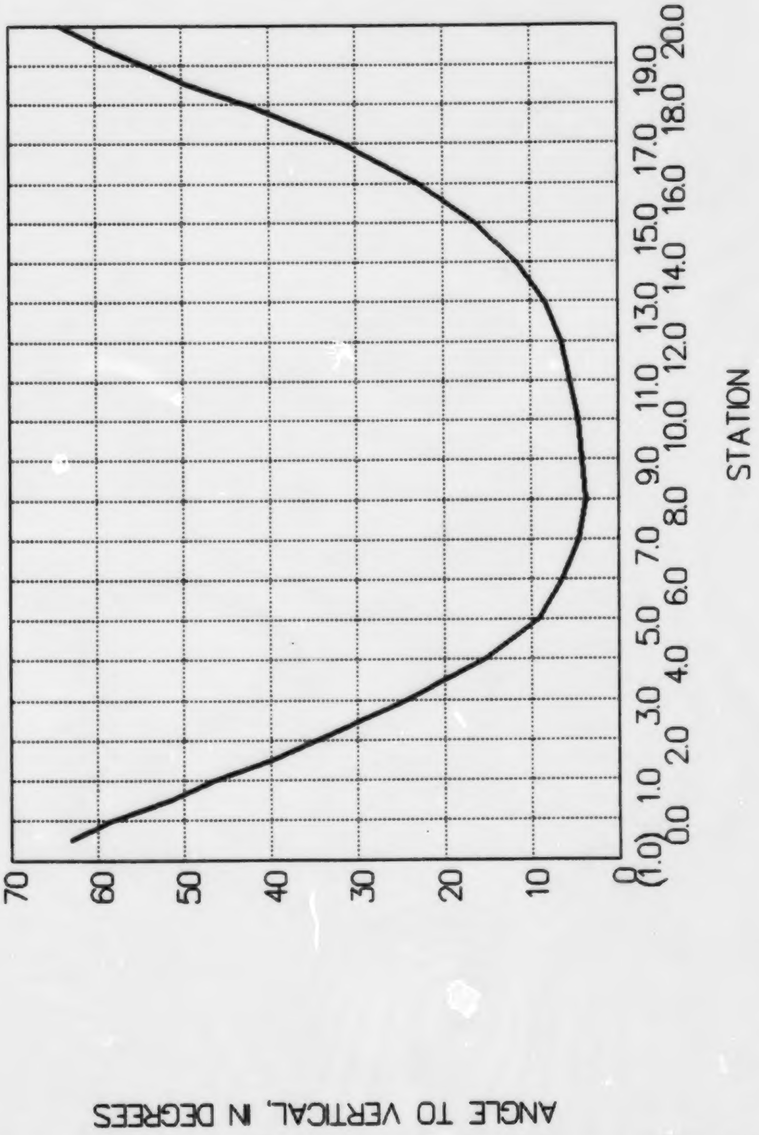

BUTTOCK ANGLE AT 8.7M WATERLINE
LOUIS S. ST LAURENT
ANGLE TO HORIZONTAL, DEG
0
10
20
30
40
50
60
70
80
90
STATION
10
11
12
13
14
15
16
17
18
19
20

Figure 13.3

# FRAME ANGLE AT WATERLINE

## LOUIS S.ST. LAURENT



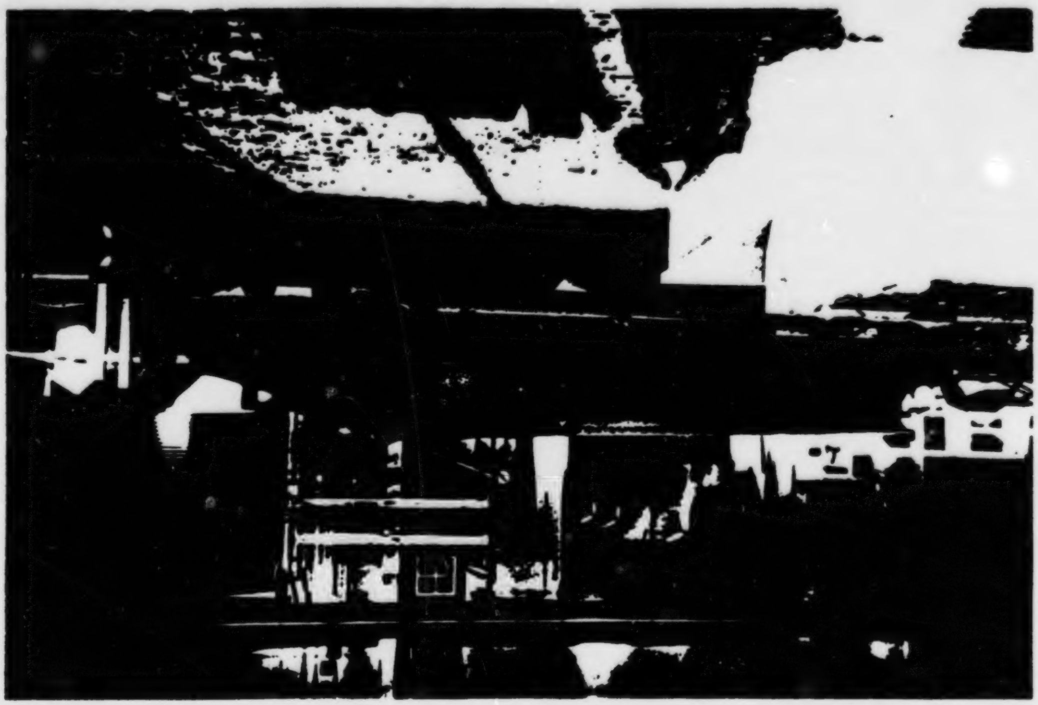


PHOTO 13.4

PHOTO 13.5

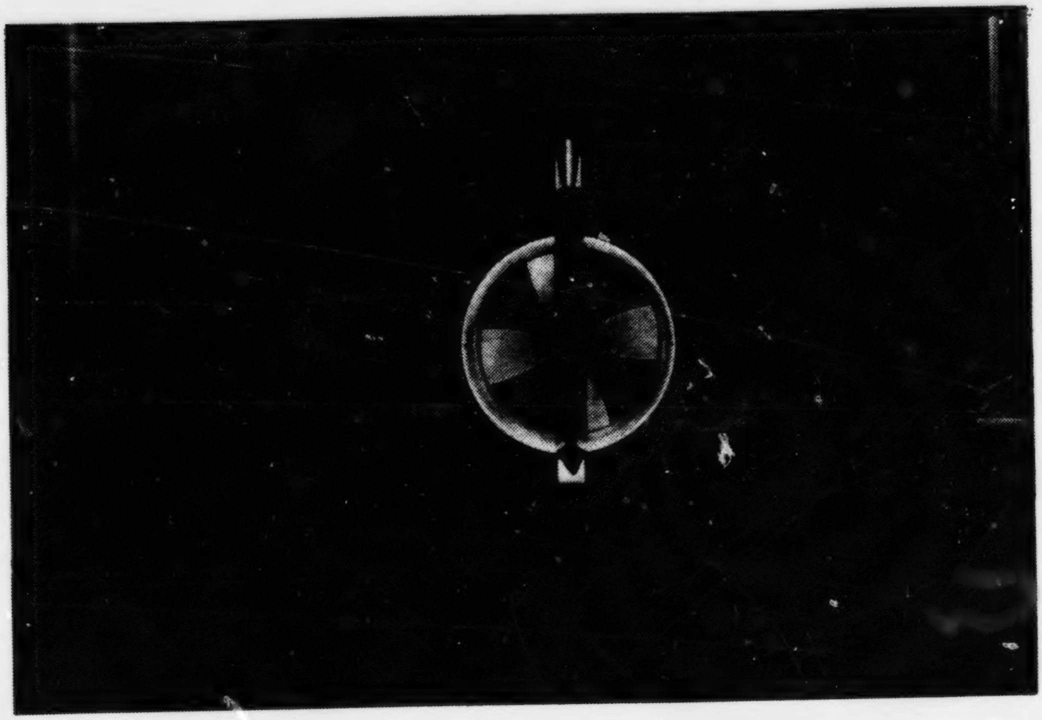


Photo 13.6 - Propellers
Arrangement - view from stern

Photo 13.7 - Stern Configuration
Ready for Testing

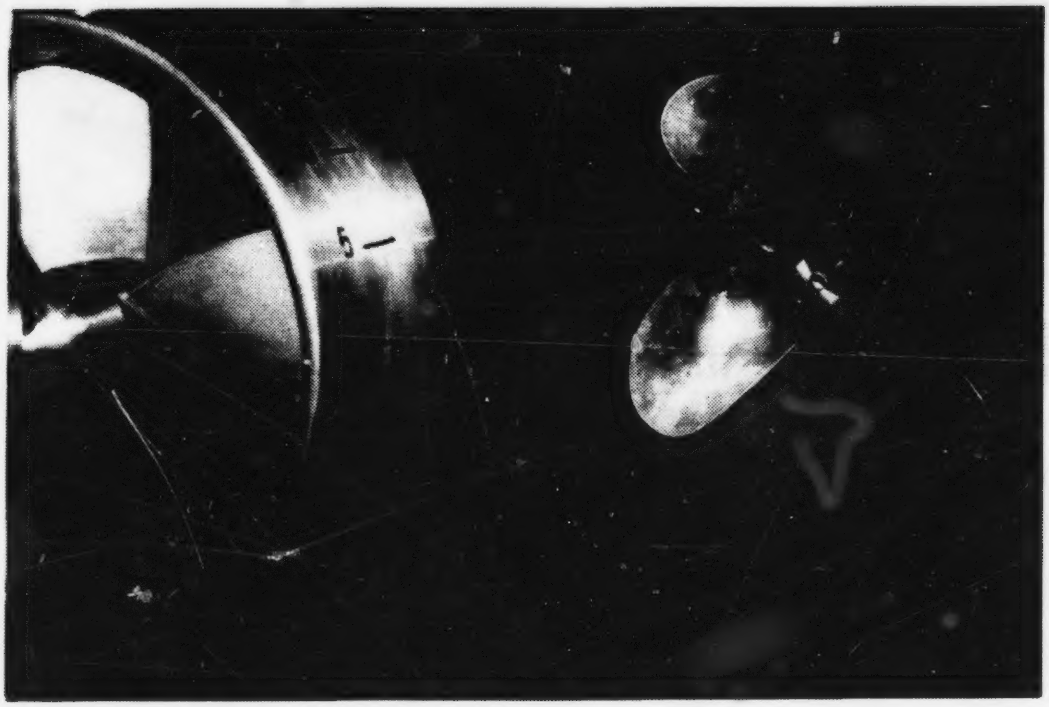
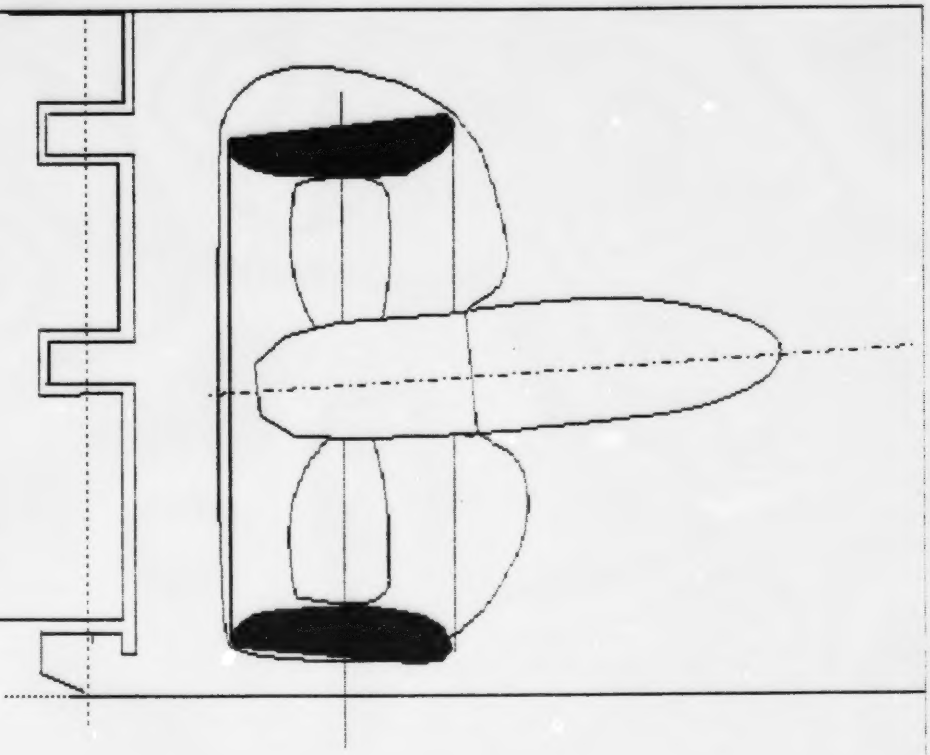


Photo 13.8 - Close-up Propeller, Nozzle, & Wing Shaft



| | | | |
|---|---|---|---|
| **FIGURE TITLE:** NOZZLE ARRANGEMENT IN THE STERN FRAME | | | |
| **PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION | | | |
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 13.9 |

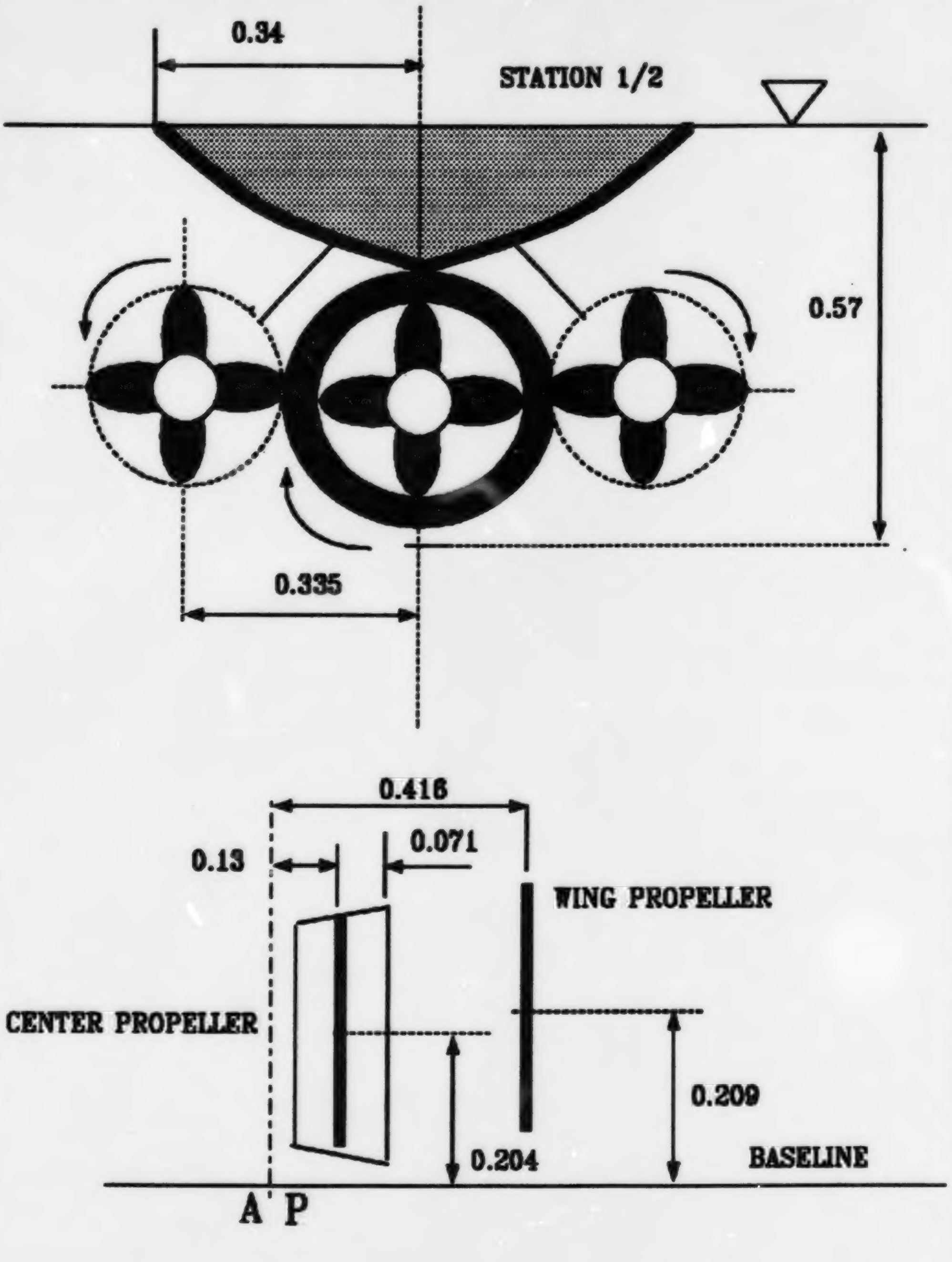
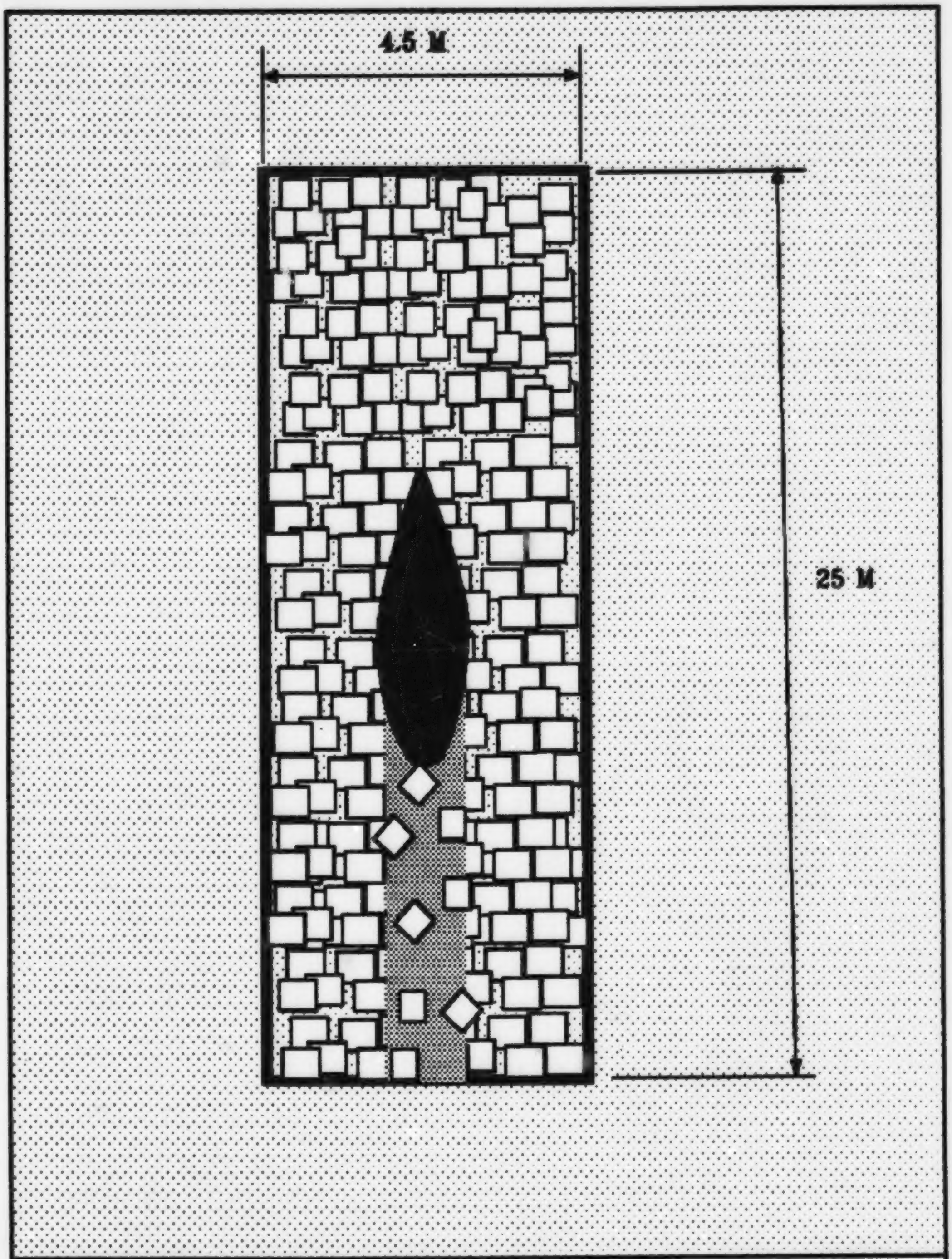


**FIGURE TITLE:** PROPELLERS/STERN ARRANGEMENT

**PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION

**DRAWN BY:** VL **CHK'D BY:** VL **SCALE:** NONE **FIGURE NR:** 13.10



| | | | |
|---|---|---|---|
| **FIGURE TITLE:** ICE CORRAL LAYOUT | | | |
| **PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION | | | |
| **DRAWN BY:** | **CHK'D BY:** | **SCALE:** | **FIGURE NR:** 13.11 |

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TABLE 13.2
SUMMARY OF THE TEST 195

| RUN NO. | SHIP STATUS SPEED KNOTS | DRAFT | SHAFTS RPS CENTRE | PORT | STRB | ICE COVER THICKNESS | COVER |
|---|---|---|---|---|---|---|---|
| 1 | (0.50) | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 2 | 1.00 | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 3 | (1.00) | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 4 | 3.00 | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 5 | (1.50) | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 6 | 5.00 | 100% | 100% | 100% | 100% | 6.7 CM | MAX |
| 7 | ZERO CHECK | | | | | | |
| 8 | (0.50) | 100% | 75% | 75% | 75% | 6.7 CM | MAX |
| 9 | | 100% | 75% | 75% | 75% | 6.7 CM | MAX |
| 10 | (1.50) | 100% | 0% | 75% | 75% | 6.7 CM | MAX |
| 11 | 3.00 | 100% | 75% | 75% | 75% | | |
| 12 | ZERO CHECK | | | | | | |
| 13 | | 100% | 50% | 50% | 50% | 6.7 CM | MAX |
| 14 | 1.00 | 100% | 50% | 50% | 50% | 6.7 CM | MAX |
| 15 | (1.50) | 100% | 0% | 50% | 50% | 6.7 CM | MAX |
| 16 | ZERO CHECK | | | | | | |
| 17 | 3.00 | 80% | 100% | 100% | 100% | 6.7 CM | MAX |
| 18 | (1.50) | 80% | 0% | 100% | 100% | 6.7 CM | MAX |
| 19 | | 80% | 100% | 100% | 100% | 6.7 CM | 90% |
| 20 | 10.00 | 80% | 100% | 100% | 100% | 6.7 CM | 60% |

## AVERAGE PROPELLER THRUST IN ICE AS FUNCTION OF RPS

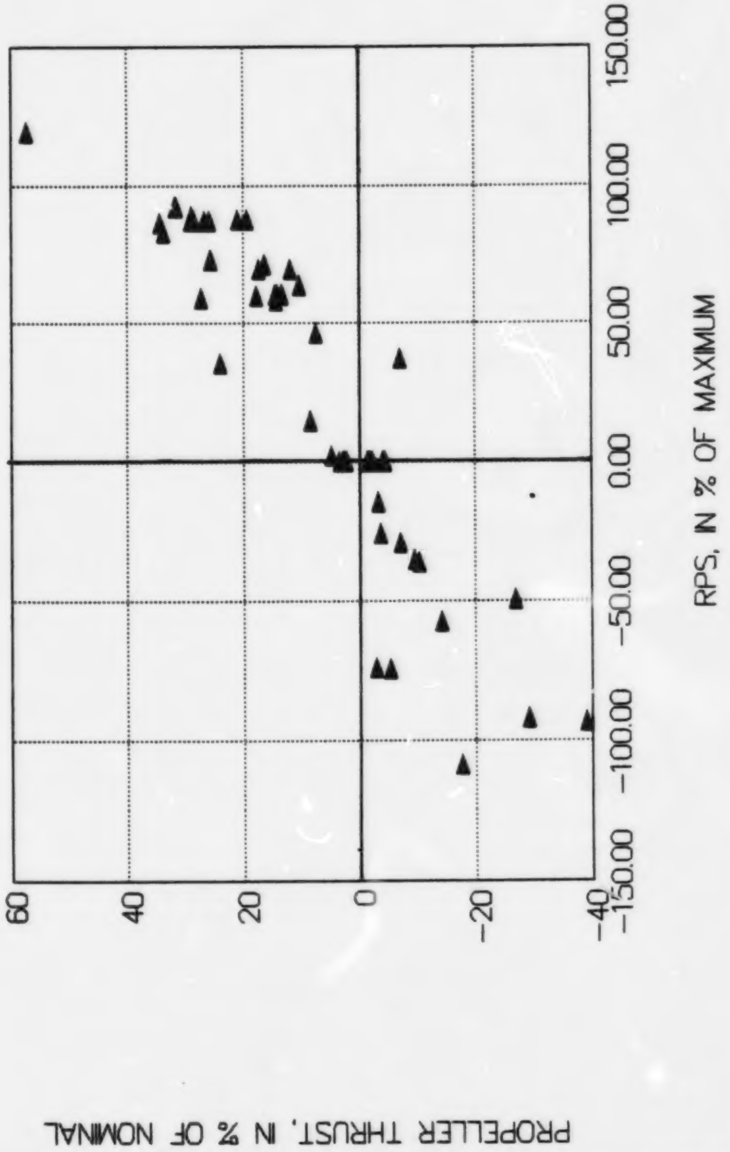


Figure 13.13

## AVERAGE NOZZLE + PROP THRUST IN ICE AS FUNCTION OF RPS

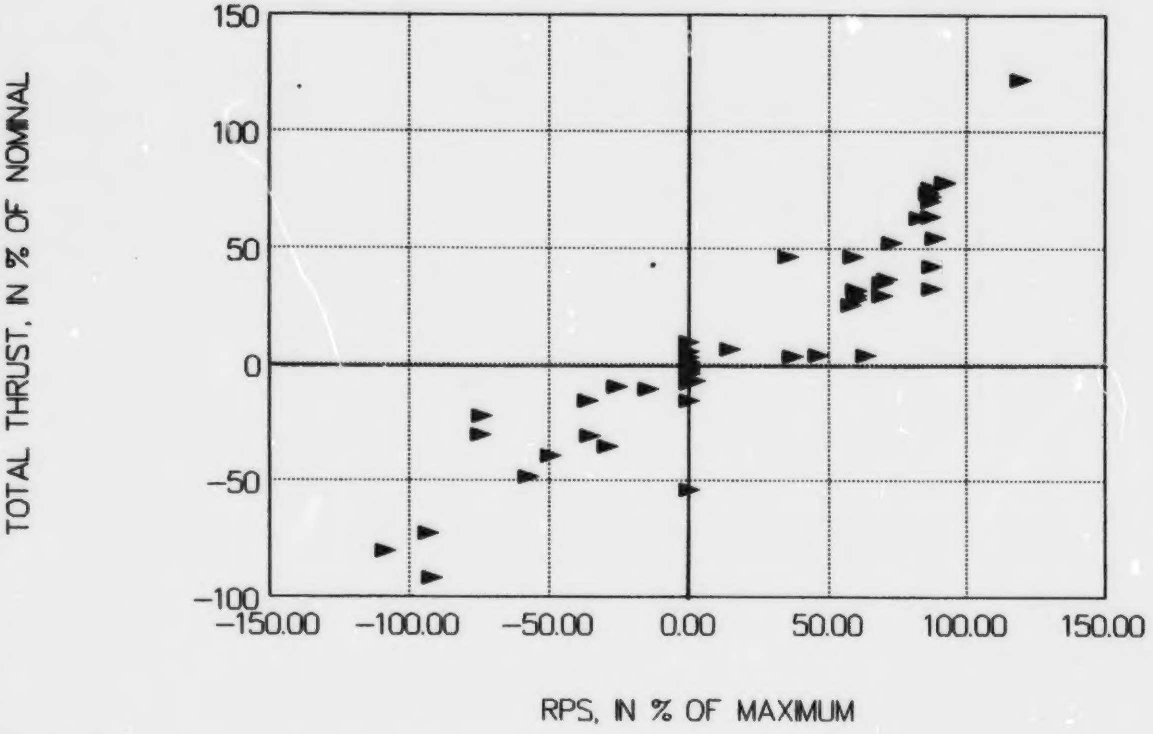
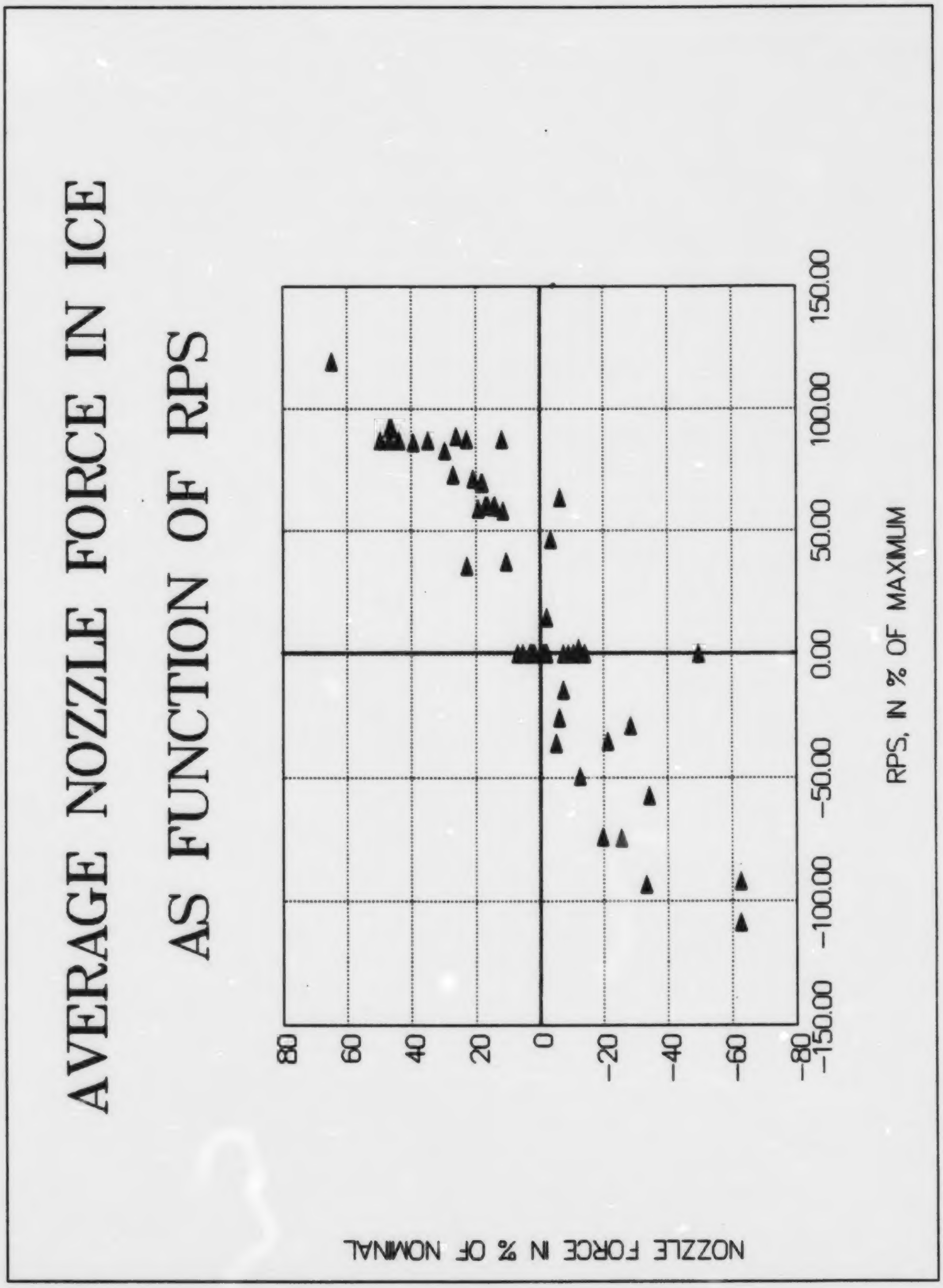


Figure 13.14



AVERAGE NOZZLE FORCE IN ICE AS FUNCTION OF RPS

Figure 13.15

## AVERAGE NOZZLE FORCE IN ICE AS FUNCTION OF MODEL SPEED

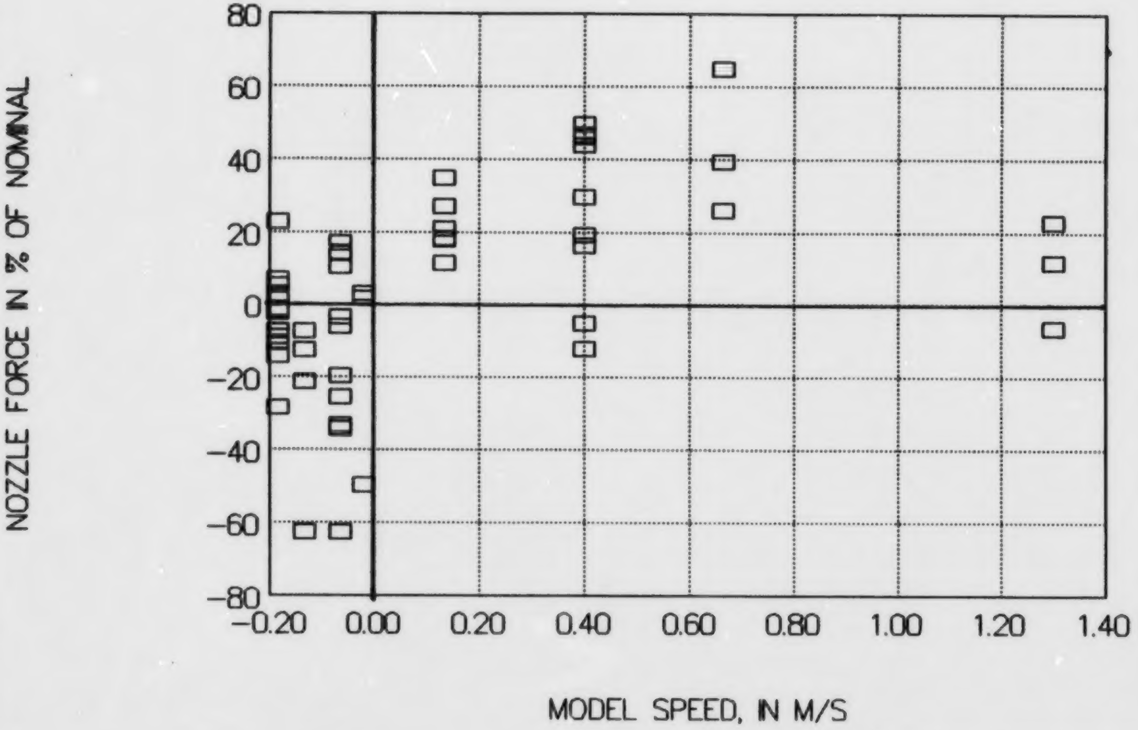


Figure 13.16

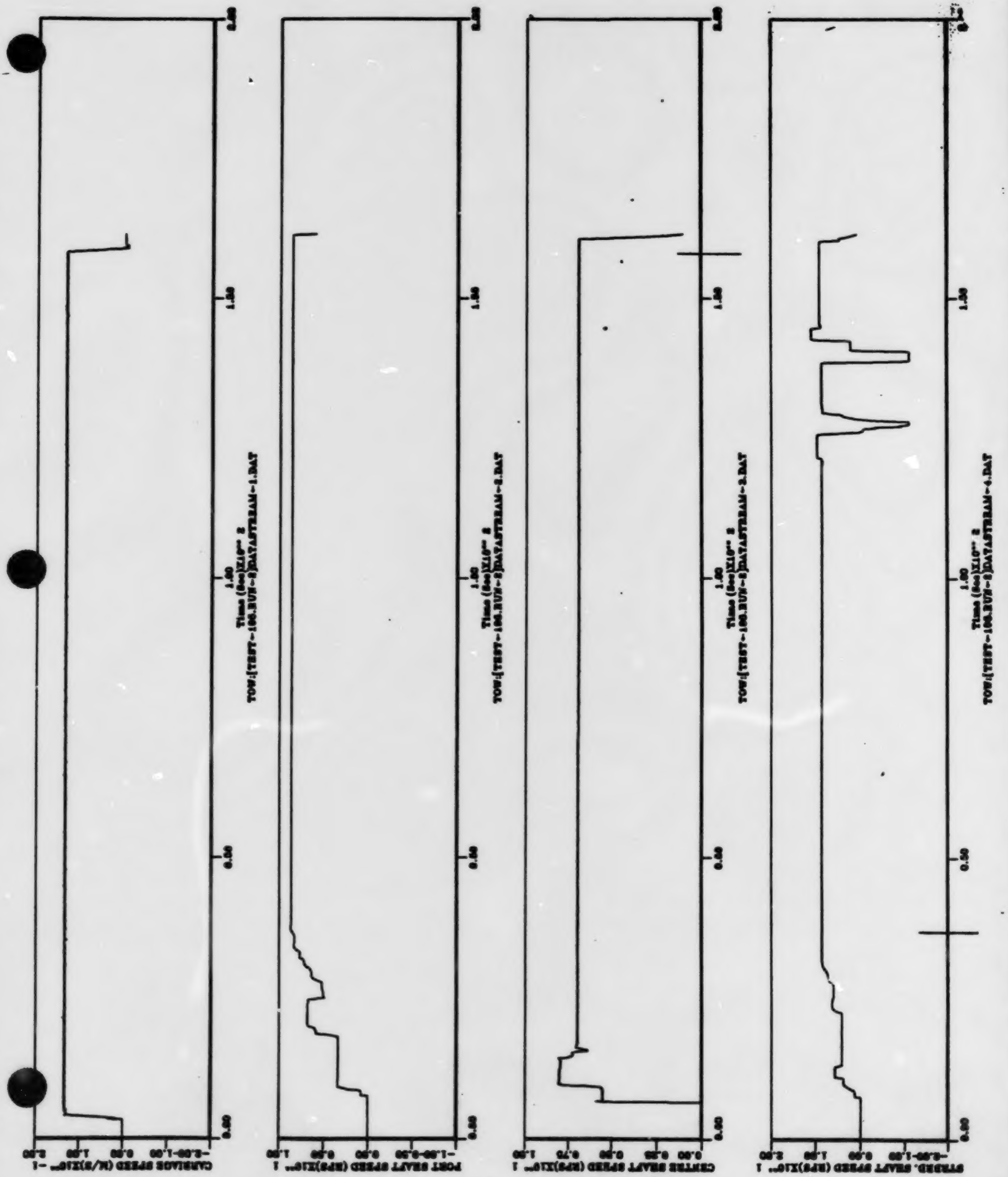
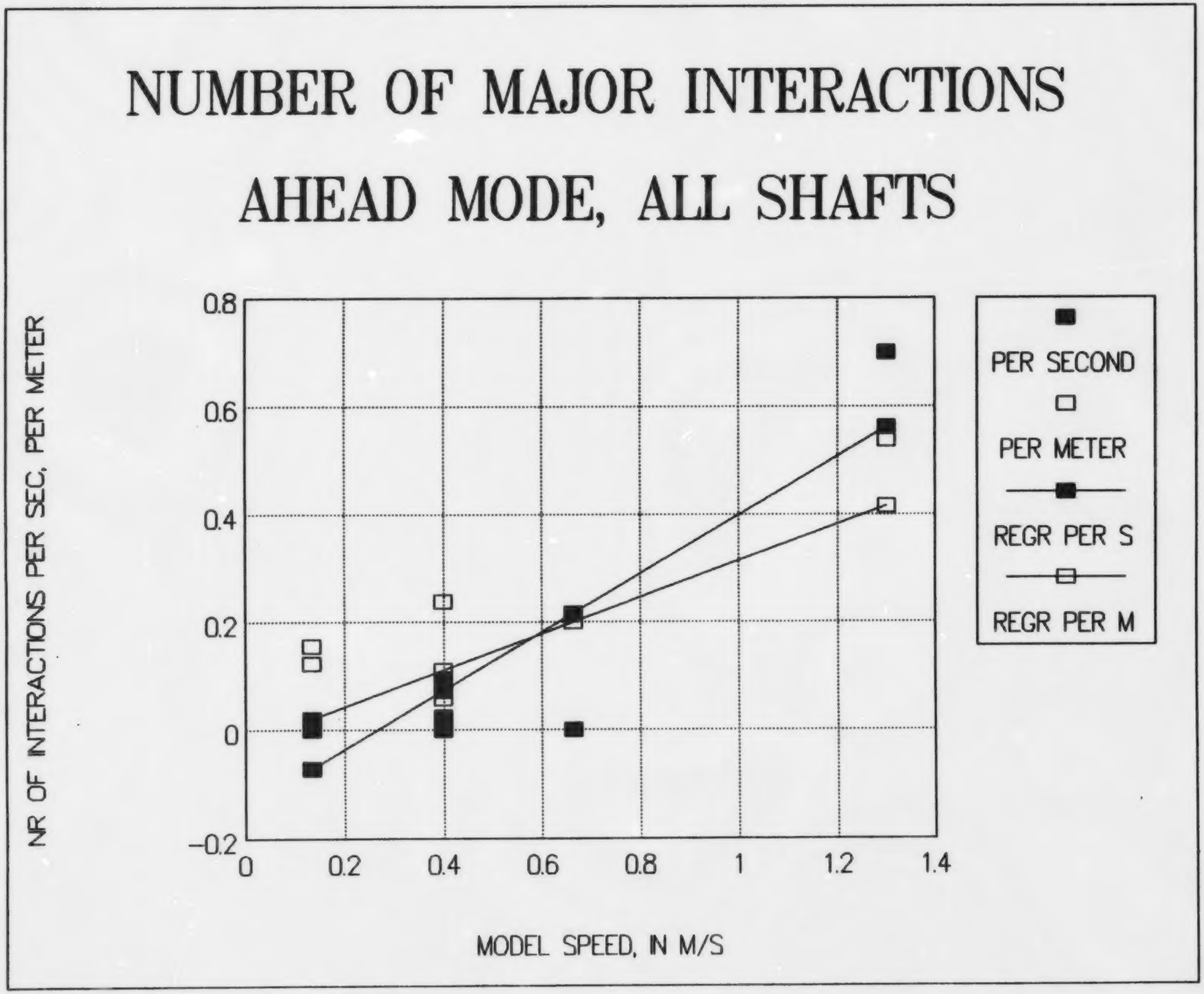

CARRIAGE SPEED (M/S)X10** 1
-2.00
-1.00
0.00
1.00
2.00
PORT SHAFT SPEED (RPS)X10** 1
-1.00
-0.50
0.00
0.50
1.00
CENTRE SHAFT SPEED (RPS)X10** 1
0.00
0.25
0.50
0.75
1.00
STBRD. SHAFT SPEED (RPS)X10** 1
-2.00
-1.00
0.00
1.00
2.00
0.00
0.50
1.00
1.50
2.00
Time (Sec)X10** 2
TOW:[TEST-100.RUN-8]DATASTREAM-1.DAT
TOW:[TEST-100.RUN-8]DATASTREAM-2.DAT
TOW:[TEST-100.RUN-8]DATASTREAM-3.DAT
TOW:[TEST-100.RUN-8]DATASTREAM-4.DAT

TABLE 13.3

SUMMARY OF ICE/PROPULSION INTERACTIONS WITH BROKEN ICE/ MAJOR EVENTS

| TEST NR | DURATION SEC | MODEL SPEED M/S | DISTANCE TRAVELLED M | NUMBER OF MAJOR INTERACTIONS |  |  |  | NUMBER OF MAJOR INTERACTIONS PER SECOND |  |  |  | PER METER |  |  |  | POWER STATUS IN PERCENT OF MAXIMUM |  |  |  | NR OF INTERACTIONS CENTER/ |  |  | AVG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | PORT | CNTR | STBD | ALL 3 | PORT | CNTR | STBD | ALL 3 | PORT | CNTR | STBD | ALL 3 | PORT | CNTR | STBD | ALL 3 | PORT | STBD | ALL 3 | WING |
|  | ASTERN |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 70.25 | -0.066 | 4.64 | 0 | 1 | 0 | 1 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.22 | 0.00 | 0.22 | -1 | -1 | -1 | -1 |  |  | 1.0 |  |
| 3 | 112.07 | -0.133 | 14.91 | 5 | 6 | 10 | 21 | 0.04 | 0.05 | 0.09 | 0.19 | 0.34 | 0.40 | 0.67 | 1.41 | -1 | -1 | -1 | -1 | 1.2 | 0.6 | 0.3 | 0.8 |
| 5 | 56.03 | -0.199 | 11.15 | 3 | 4 | 6 | 13 | 0.05 | 0.07 | 0.11 | 0.23 | 0.27 | 0.36 | 0.54 | 1.17 | -1 | -1 | -1 | -1 | 1.3 | 0.7 | 0.3 | 0.9 |
| 8 | 126.29 | -0.066 | 8.34 | 3 | 6 | 3 | 12 | 0.02 | 0.05 | 0.02 | 0.10 | 0.36 | 0.72 | 0.36 | 1.44 | -0.75 | -0.75 | -0.75 | -0.75 | 2.0 | 2.0 | 0.5 | 2.0 |
| 10 | 60.34 | -0.199 | 12.01 | 4 | 1 | 5 | 10 | 0.07 | 0.02 | 0.08 | 0.17 | 0.33 | 0.08 | 0.42 | 0.83 | -0.75 | 0 | -0.75 | -0.5 | 0.3 | 0.2 | 0.1 | 0.2 |
| 13 | 87.5 | -0.066 | 5.78 | 1 | 0 | 2 | 3 | 0.01 | 0.00 | 0.02 | 0.03 | 0.17 | 0.00 | 0.35 | 0.52 | -0.5 | 0.5 | -0.5 | -0.17 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 60.56 | -0.199 | 12.05 | 6 | 8 | 4 | 18 | 0.10 | 0.13 | 0.07 | 0.30 | 0.50 | 0.66 | 0.33 | 1.49 | -0.5 | 0 | -0.5 | -0.33 | 1.3 | 2.0 | 0.4 | 1.6 |
| 18 | 36.62 | -0.199 | 7.29 | 4 | 5 | 6 | 15 | 0.11 | 0.14 | 0.16 | 0.41 | 0.55 | 0.69 | 0.82 | 2.06 | -1 | 0 | -1 | -0.67 | 1.3 | 0.8 | 0.3 | 1.0 |
| AVG | 76.2 | (0.1) | 9.5 | 3.25 | 3.88 | 4.50 | 12 | 0.05 | 0.06 | 0.07 | 0.18 | 0.31 | 0.39 | 0.44 | 1.14 | (0.81) | (0.41) | (0.81) | (0.68) | 1.05 | 0.90 | 0.37 | 0.93 |
|  | AHEAD |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | 121.55 | 0.133 | 16.17 | 0 | 0 | 2 | 2 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.00 | 0.12 | 0.12 | 1 | 1 | 1 | 1 | 1.0 | 0.0 | 0.0 | 0.0 |
| 4 | 25.43 | 0.399 | 10.15 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | 1 | 1 | 1 | 1.0 | 1.0 | 1.0 | 1.0 |
| 6 | 28 | 0.664 | 18.59 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | 1 | 1 | 1 | 1.0 | 1.0 | 1.0 | 1.0 |
| 9 | 144.83 | 0.133 | 19.26 | 1 | 1 | 1 | 3 | 0.01 | 0.01 | 0.01 | 0.02 | 0.05 | 0.05 | 0.05 | 0.16 | 0.75 | 0.75 | 0.75 | 0.75 | 1.0 | 1.0 | 0.3 | 1.0 |
| 11 | 42.24 | 0.399 | 16.85 | 1 | 2 | 1 | 4 | 0.02 | 0.05 | 0.02 | 0.09 | 0.06 | 0.12 | 0.06 | 0.24 | 0.75 | 0.75 | 0.75 | 0.75 | 2.0 | 2.0 | 0.5 | 2.0 |
| 14 | 125.86 | 0.133 | 16.74 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 1.0 |
| 17 | 46.33 | 0.399 | 18.49 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | 1 | 1 | 1 | 1.0 | 1.0 | 1.0 | 1.0 |
| 19 | 42.67 | 0.399 | 17.03 | 0 | 0 | 1 | 1 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.00 | 0.06 | 0.06 | 1 | 1 | 1 | 1 | 1.0 | 0.0 | 0.0 | 0.0 |
| 20 | 15.7 | 1.3 | 20.41 | 3 | 3 | 5 | 11 | 0.19 | 0.19 | 0.32 | 0.70 | 0.15 | 0.15 | 0.24 | 0.54 | 1 | 1 | 1 | 1 | 1.0 | 0.6 | 0.3 | 0.8 |
| AVG | 65.8 | 0.4 | 17.1 | 0.56 | 0.67 | 1.11 | 2.33 | 0.02 | 0.03 | 0.04 | 0.10 | 0.03 | 0.04 | 0.06 | 0.12 | 0.89 | 0.89 | 0.89 | 0.89 | 1.11 | 0.84 | 0.57 | 0.86 |
| TOTAL | 1,202 |  | 230 | 31 | 37 | 46 | 114 | 1 | 1 | 1 | 2 | 3 | 3 | 4 | 10 |  |  |  |  |  |  |  |  |

Figure 13.17



NUMBER OF MAJOR INTERACTIONS
AHEAD MODE, ALL SHAFTS

Figure 13.18

NUMBER OF MAJOR INTERACTIONS

ASTERN MODE, ALL SHAFTS

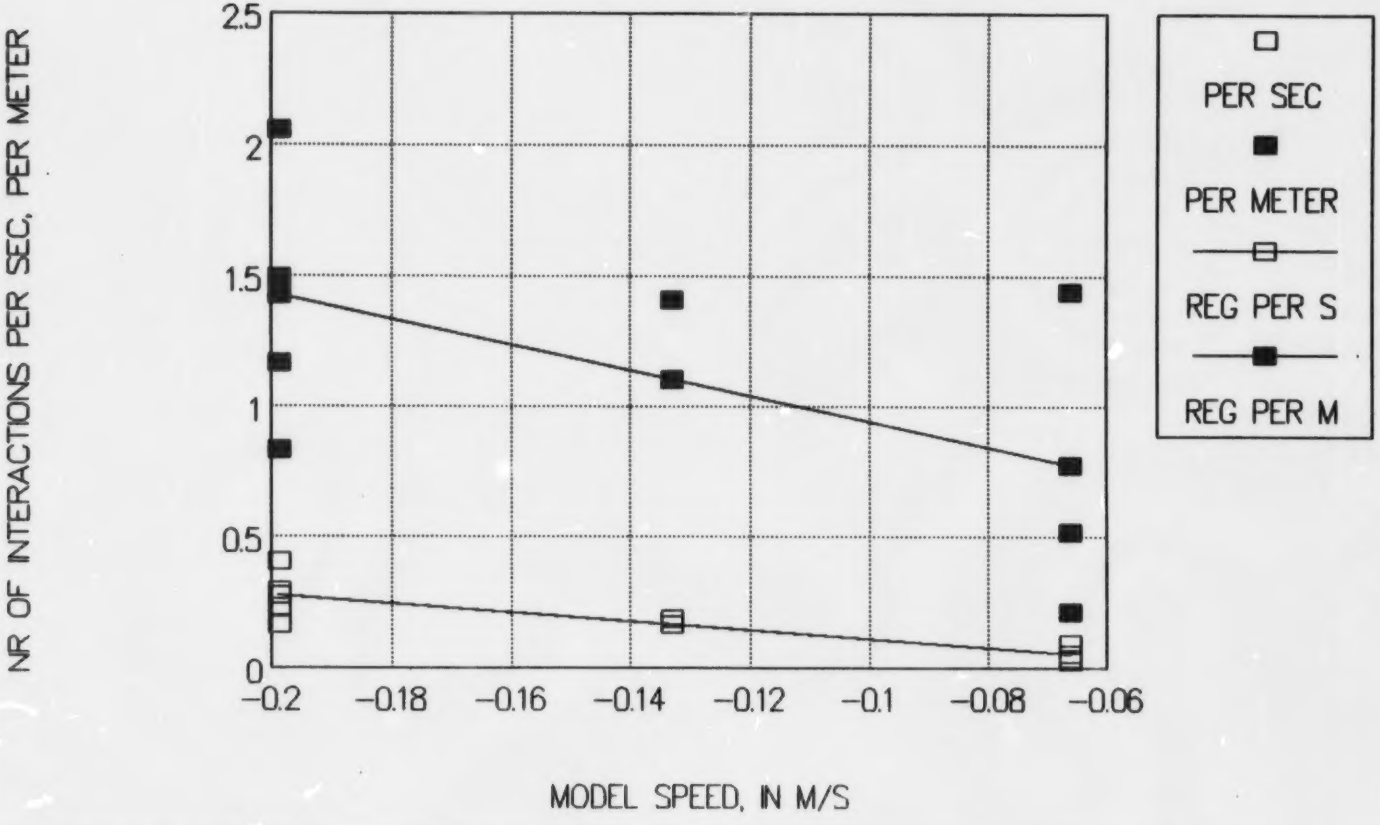


TABLE 13.4

### NR OF INTERACTIONS/SEC - ASTERN

```
          Regression Output:
Constant                        -0.06148
Std Err of Y Est                0.077954
R Squared                       0.709143
No. of Observations                    8
Degrees of Freedom                     6

X Coefficient(s)   -1.71018
Std Err of Coef.   0.447136
```

### NR OF INTERACTIONS/SEC - AHEAD MODE

```
          Regression Output:
Constant                         -0.1439
Std Err of Y Est                 0.12018
R Squared                       0.759112
No. of Observations                    9
Degrees of Freedom                     7

X Coefficient(s)   0.543332
Std Err of Coef.   0.115683
```

### NR OF INTERACTIONS/METER - ASTERN

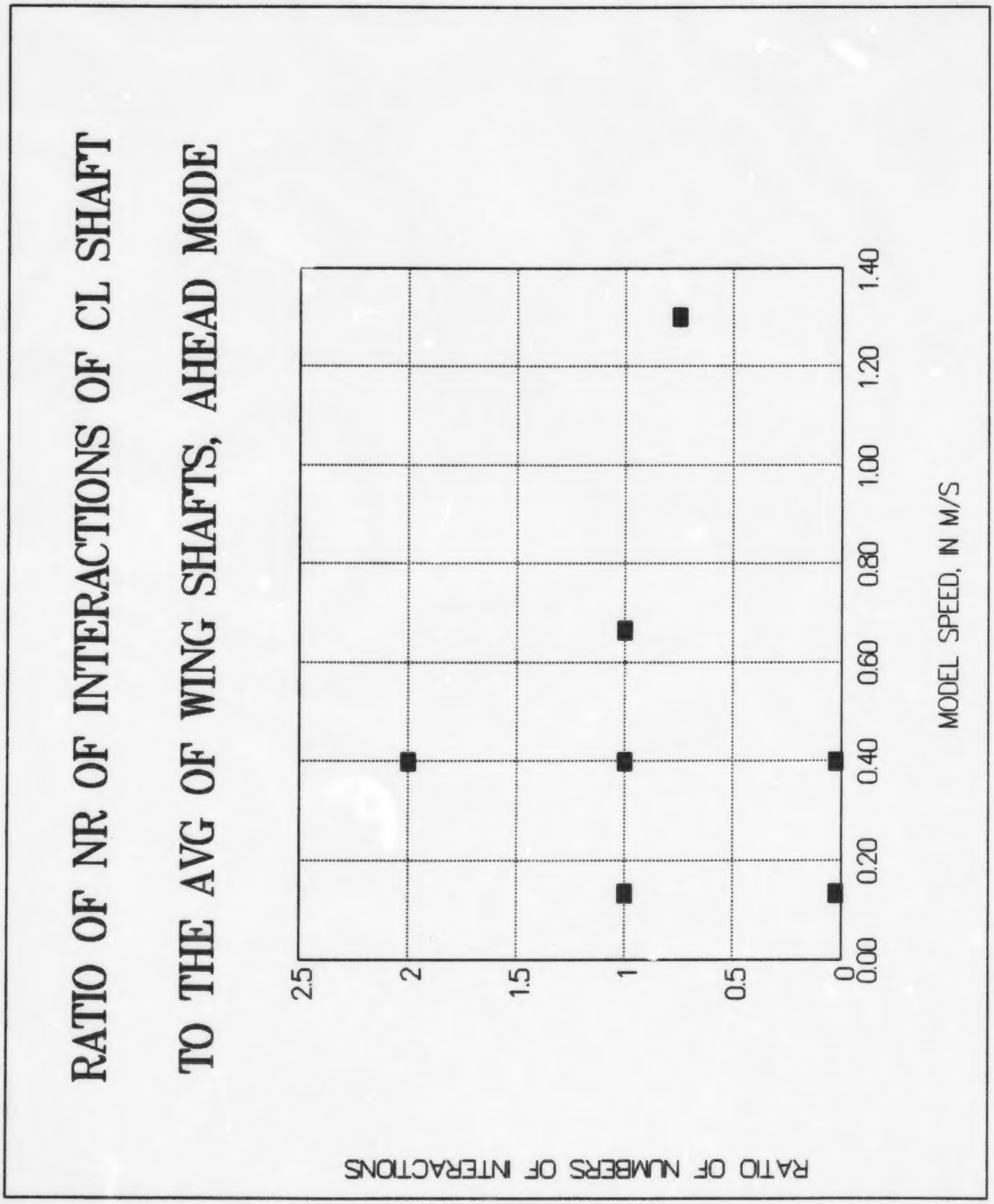
```
          Regression Output:
Constant                        0.452621
Std Err of Y Est                 0.53813
R Squared                       0.295115
No. of Observations                    8
Degrees of Freedom                     6

X Coefficient(s)   -4.89215
Std Err of Coef.   3.086649
```

### NR OF INTERACTIONS/METER -AHEAD MODE

```
          Regression Output:
Constant                        -0.02522
Std Err of Y Est                0.135167
R Squared                       0.492092
No. of Observations                    9
Degrees of Freedom                     7

X Coefficient(s)   0.338837
Std Err of Coef.    0.13011
```



RATIO OF NR OF INTERACTIONS OF CL SHAFT TO THE AVG OF WING SHAFTS, AHEAD MODE

Figure 13.20

RATIO OF NR OF INTERACTIONS OF CL SHAFT TO THE AVG OF WING SHAFTS, ASTERN MODE

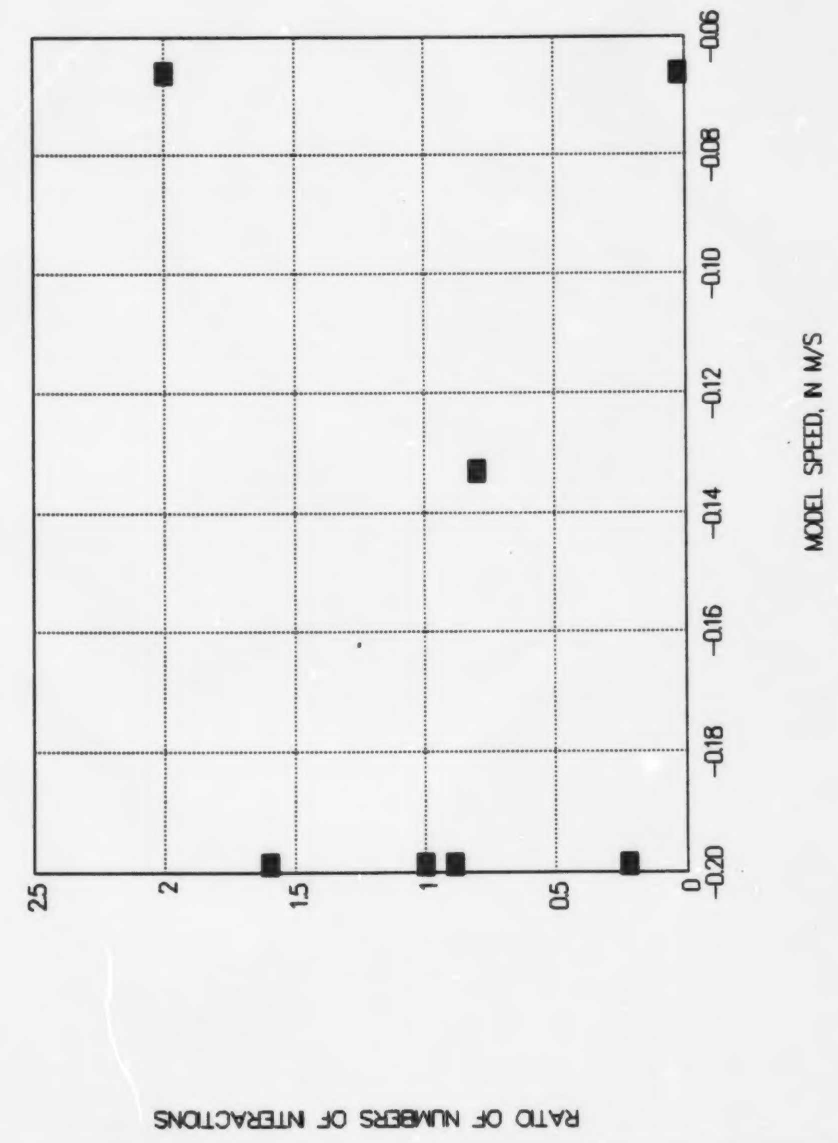


Figure 13.21

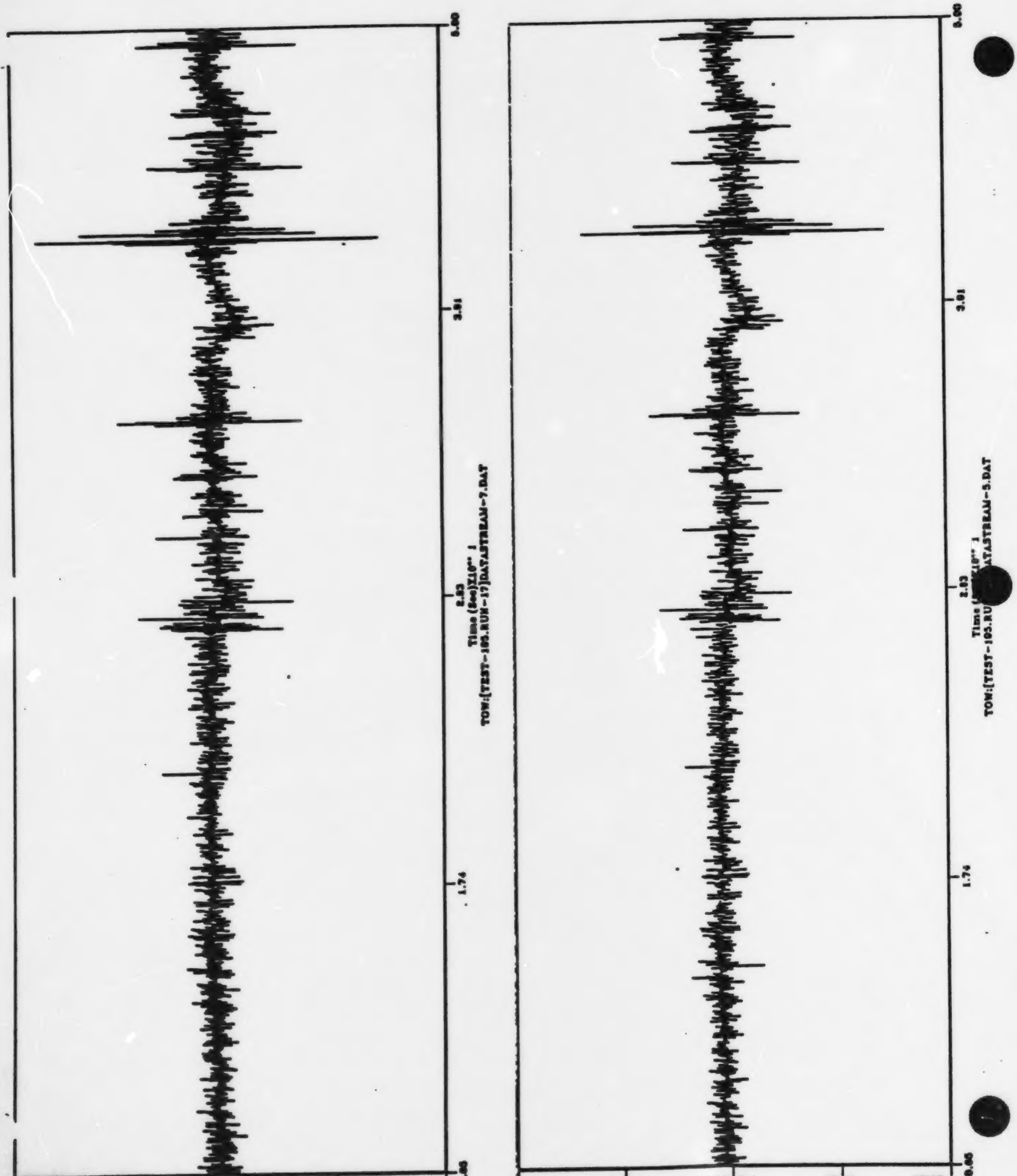

0.00
1.74
2.83
3.91
5.00
Time (Sec)X10** 1
TOW:[TEST-105.RUN-17]DATASTREAM-7.DAT
0.00
-12.50
-25.00
-37.50
-50.00
NOZZLE BH [#2 GAUGE] (Kms)
0.00
1.74
2.83
3.91
5.00
Time
TOW:[TEST-105.RU ATASTREAM-5.DAT
0.00
-12.50
-25.00
-37.50
-50.00
NOZZLE BH [#1 GAUGE] (Kms)

Figure 13.22

# NUMBER OF IMPACTS ON THE NOZZLE AS A FUNCTION OF MEAN POWER

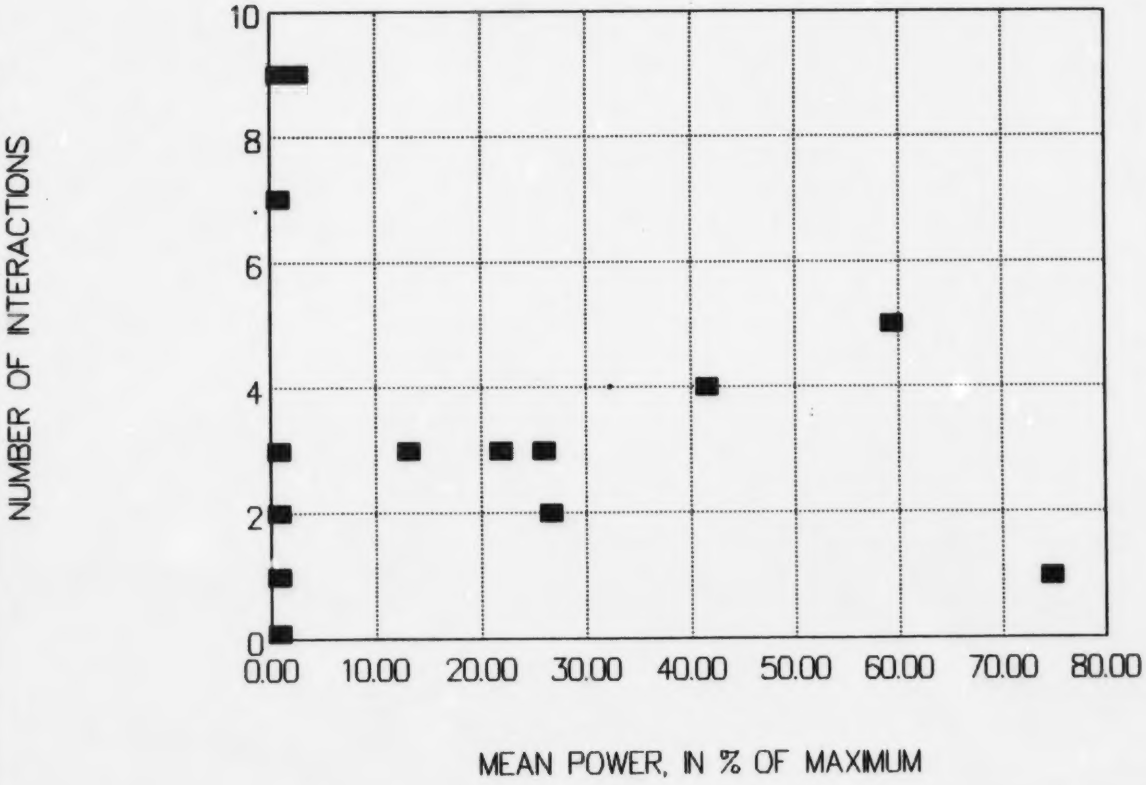
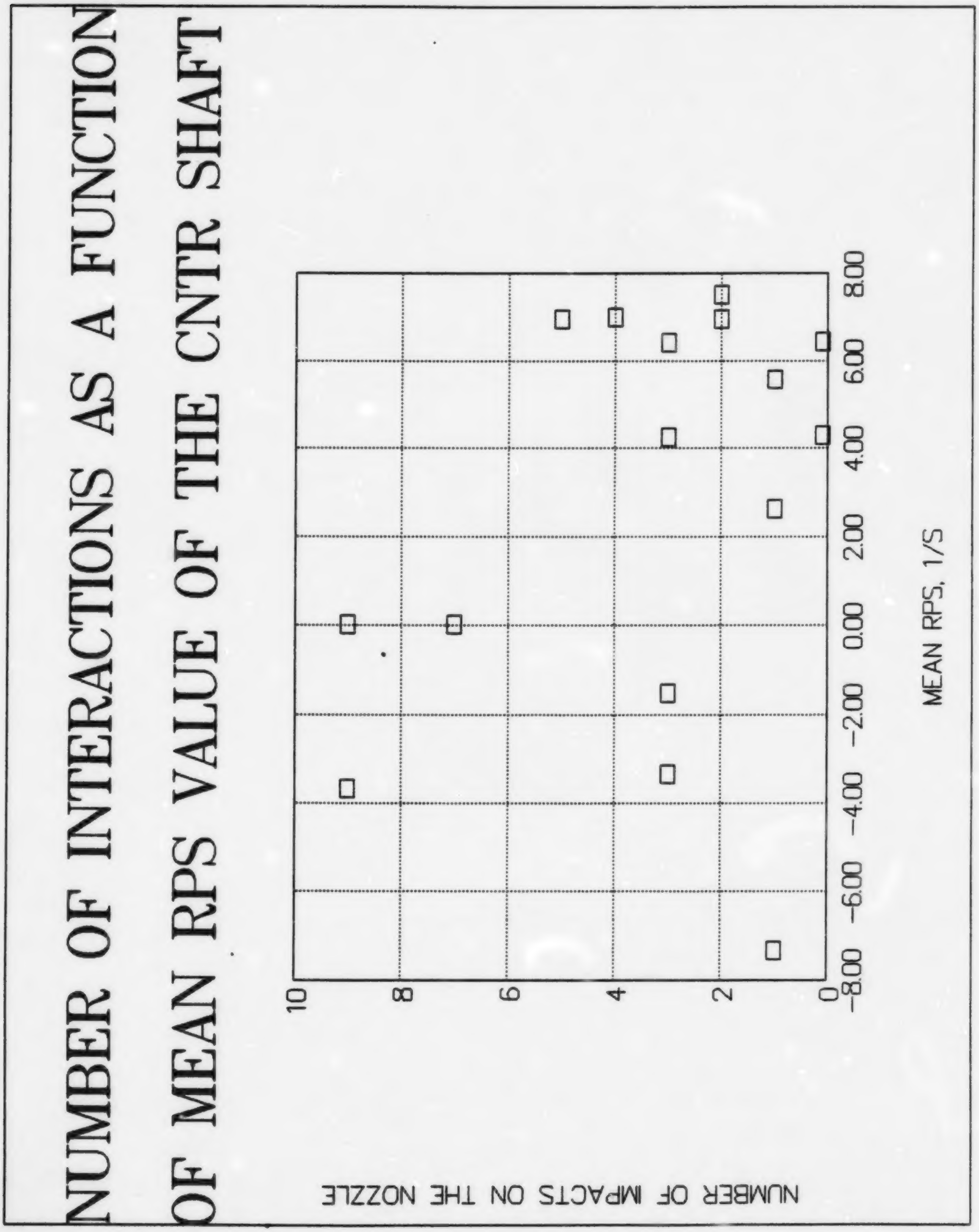


Figure 13.23



NUMBER OF INTERACTIONS AS A FUNCTION OF MEAN RPS VALUE OF THE CNTR SHAFT

NUMBER OF INTERACTIONS AS A FUNCTION OF MEAN TORQUE OF THE CENTER SHAFT

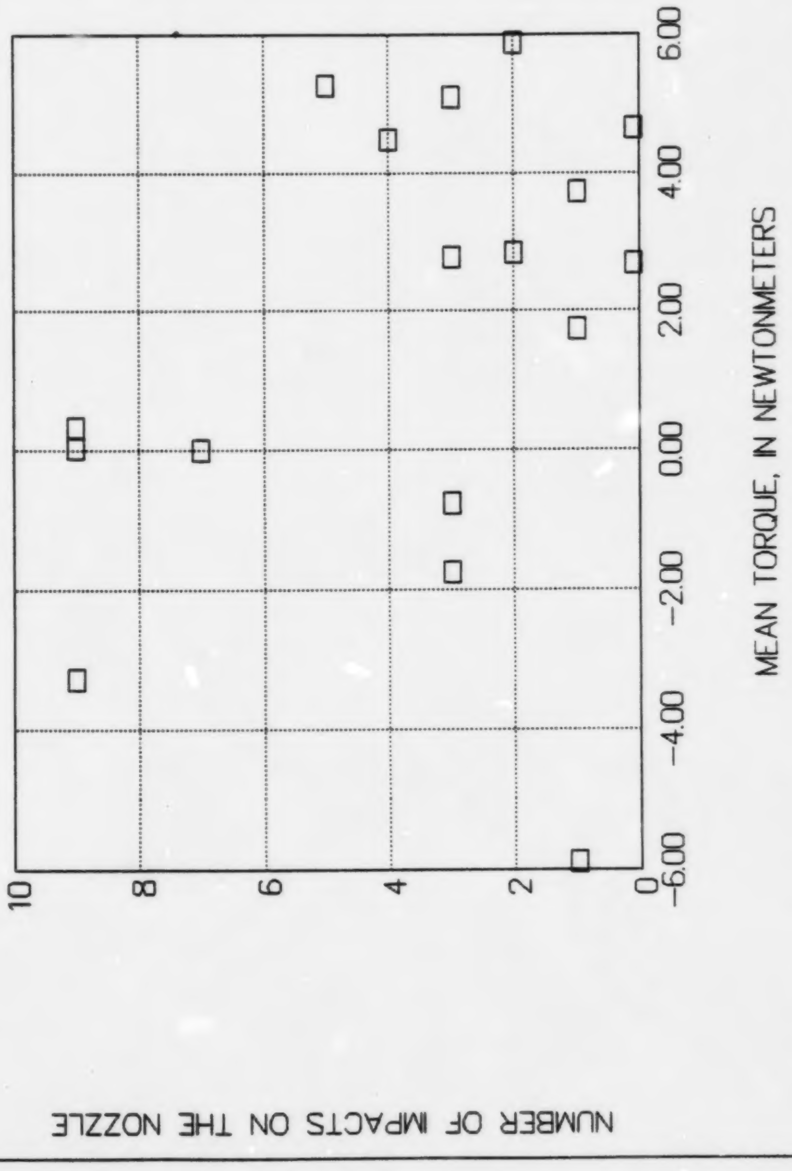
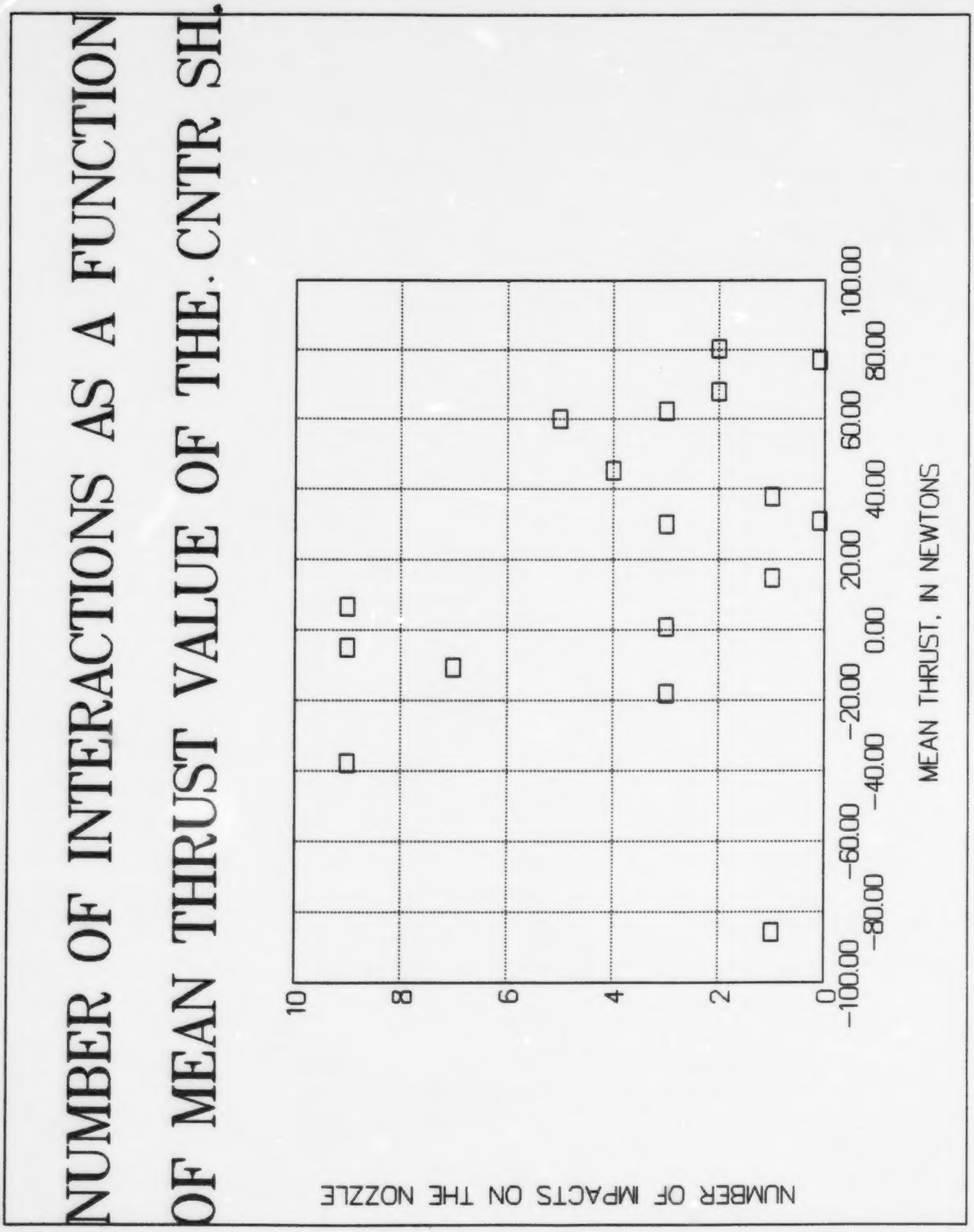
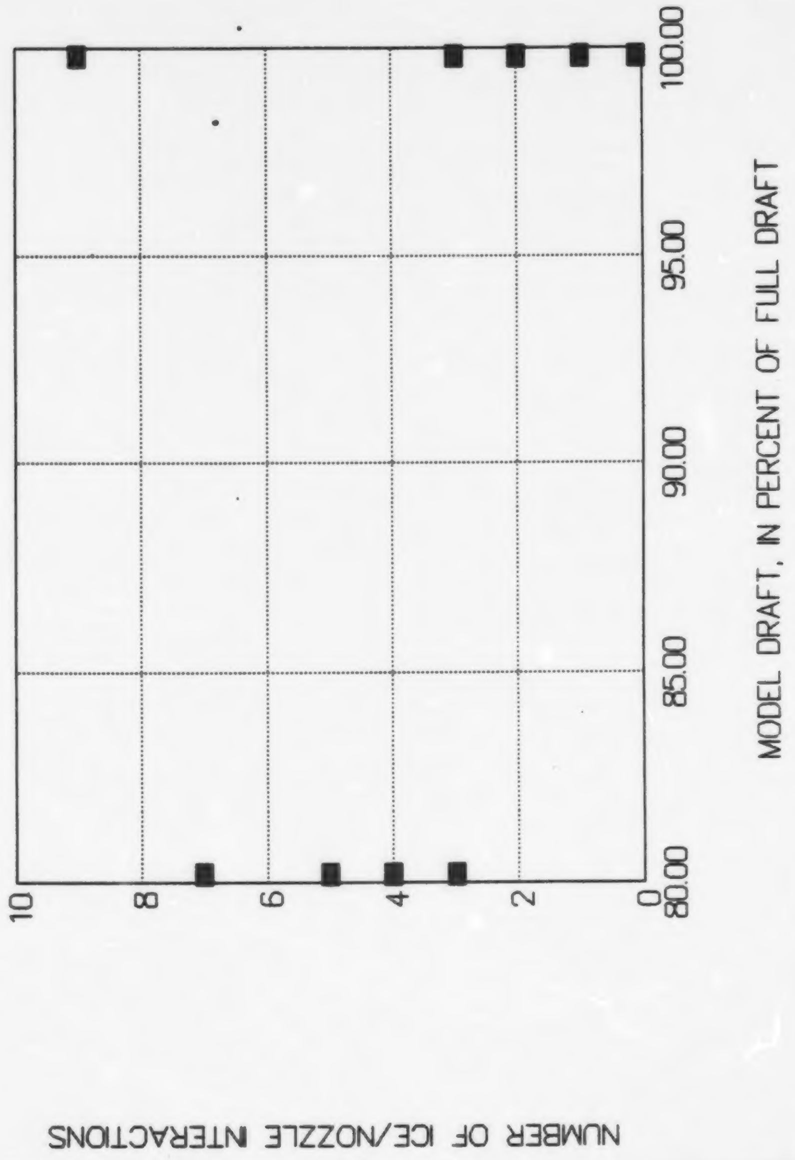
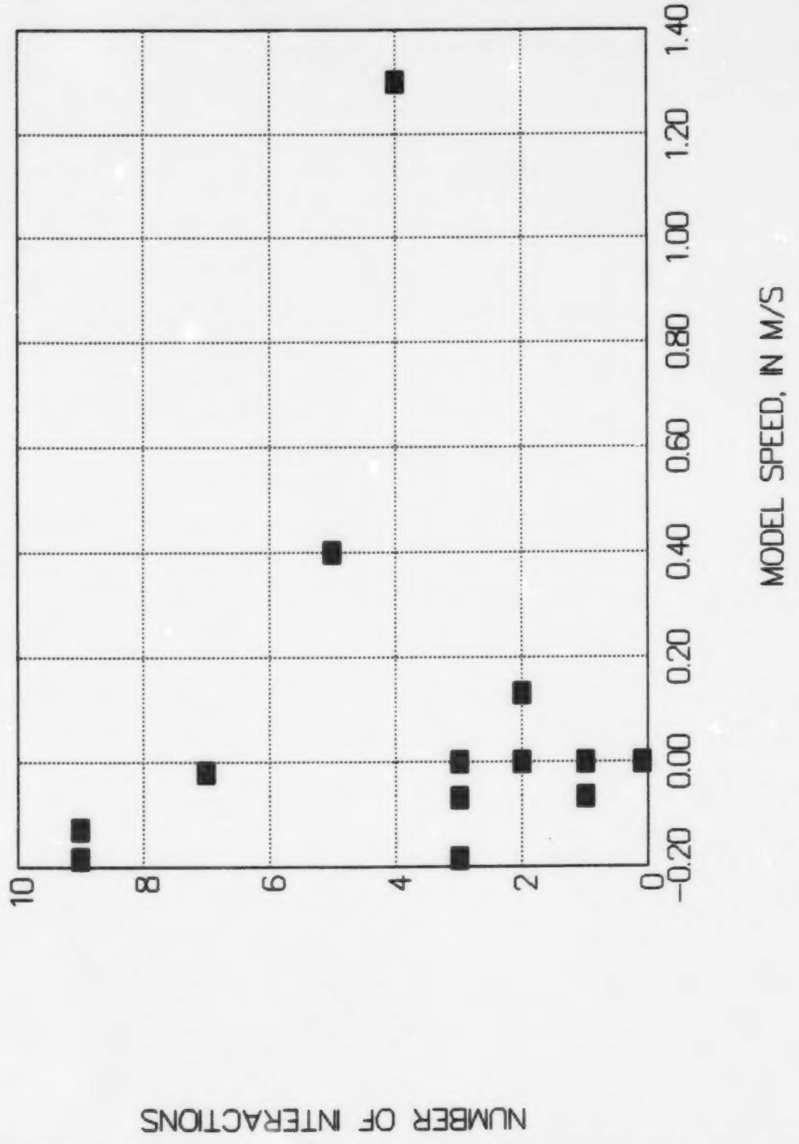


Figure 13.25


NUMBER OF INTERACTIONS AS A FUNCTION OF MEAN THRUST VALUE OF THE. CNTR SH.

NUMBER OF INTERACTIONS
AS A FUNCTION OF MODEL DRAFT

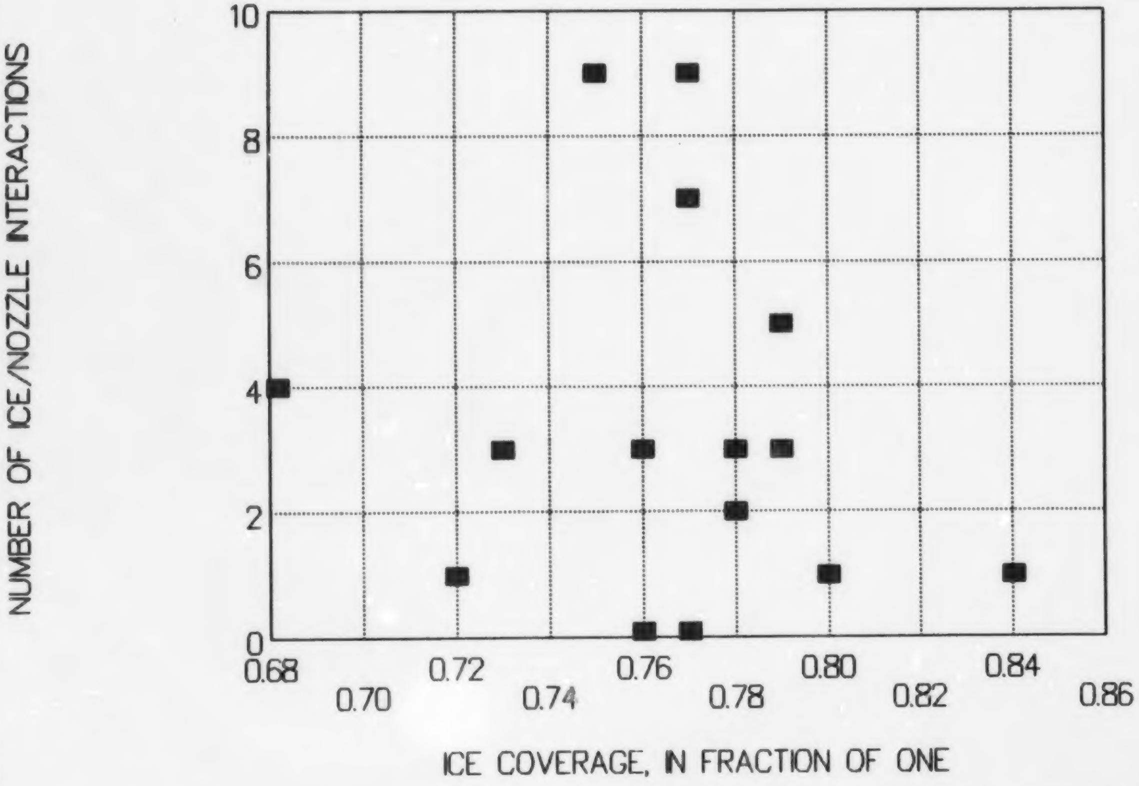




NUMBER OF IMPACTS ON THE NOZZLE AS A FUNCTION OF MODEL SPEED

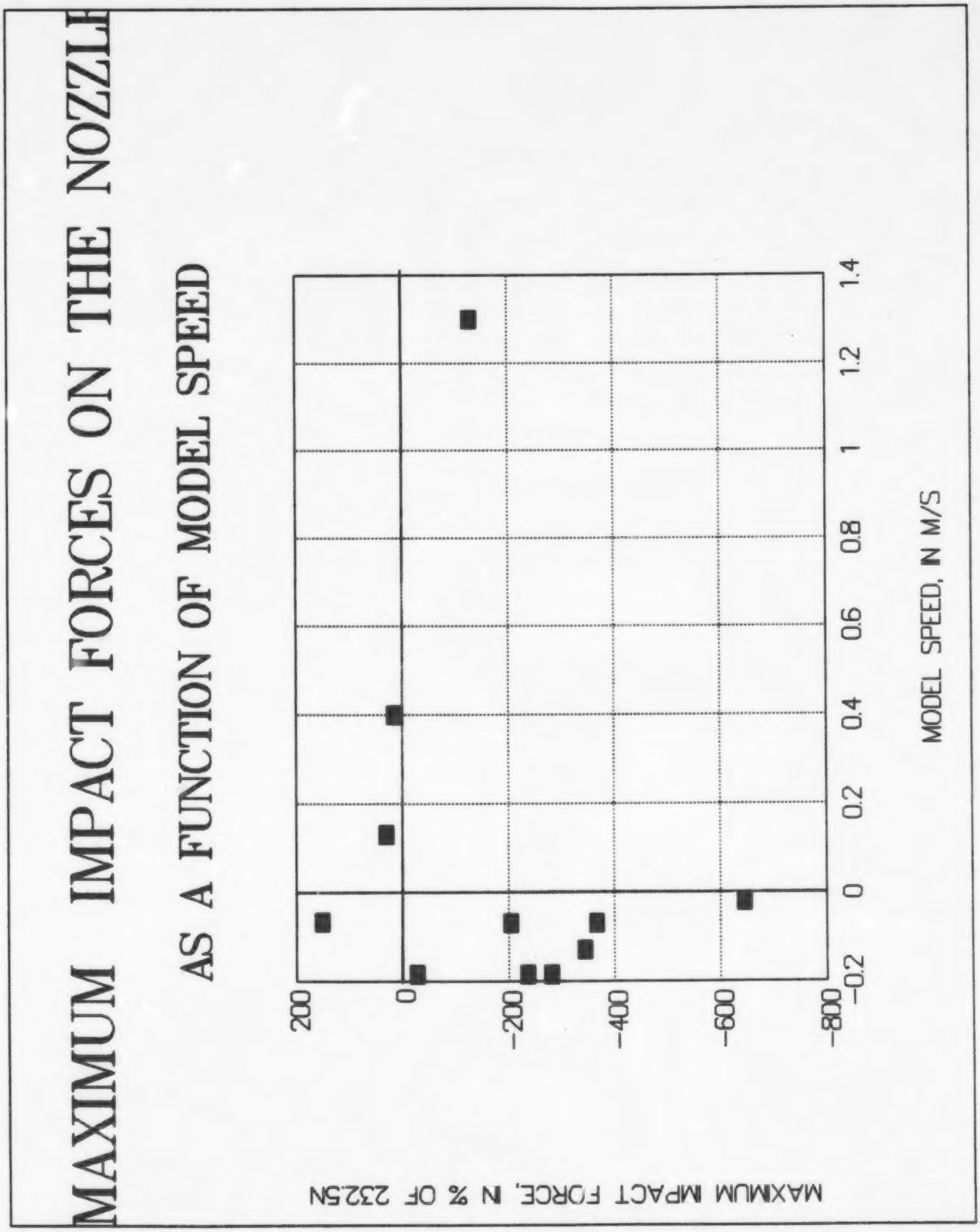
Figure 13.28

NUMBER OF INTERACTIONS
AS A FUNCTION OF ICE COVERAGE



## TABLE 13.5
## SUMMARY OF MAXIMUM IMPACT FORCES

| PEAK BENDING MOMENT, IN NM 1 | 3 | LARGEST N | FORCE IN % OF NOMI | MODEL SPEED M/S | POWER DEVEL'D % MAX | CENTER SHAFT SPEED | TOTAL THRUST | DRAFT IN % OF MA |
|---|---|---|---|---|---|---|---|---|
| (108.00) | (122.00) | 350 | 151 | (0.07) | 74.71 | -74.38 | -22.39 | 100 |
| (8.00) | (10.70) | 67 | 29 | 0.13 | 26.63 | 86.95 | 63.4 | 100 |
| 118.00 | 150.00 | (800) | (344) | (0.13) | 2.54 | -14.59 | -10.5 | 100 |
| 207.00 | 233.00 | (650) | (280) | (0.20) | 13.12 | 35.58 | 46.53 | 100 |
| 286.00 | 320.00 | (850) | (366) | (0.07) | 21.86 | -57.33 | -48.41 | 100 |
| 156.00 | 178.00 | (550) | (237) | (0.20) | 0 | 0.24 | 0.71 | 100 |
| 55.00 | 74.00 | (475) | (204) | (0.07) | 26.04 | 59.92 | 32.03 | 100 |
| (18.20) | (15.50) | (67) | (29) | (0.20) | 0.01 | 0.24 | 9.64 | 100 |
| (17.70) | (19.00) | 33 | 14 | 0.40 | 59.36 | 86.74 | 70.36 | 80 |
| 85.00 | 145.00 | (1,500) | (645) | (0.02) | 0 | 0.24 | -54.01 | 80 |
| 62.00 | 74.00 | (300) | (129) | 1.30 | 41.55 | 63.32 | 4.02 | 80 |



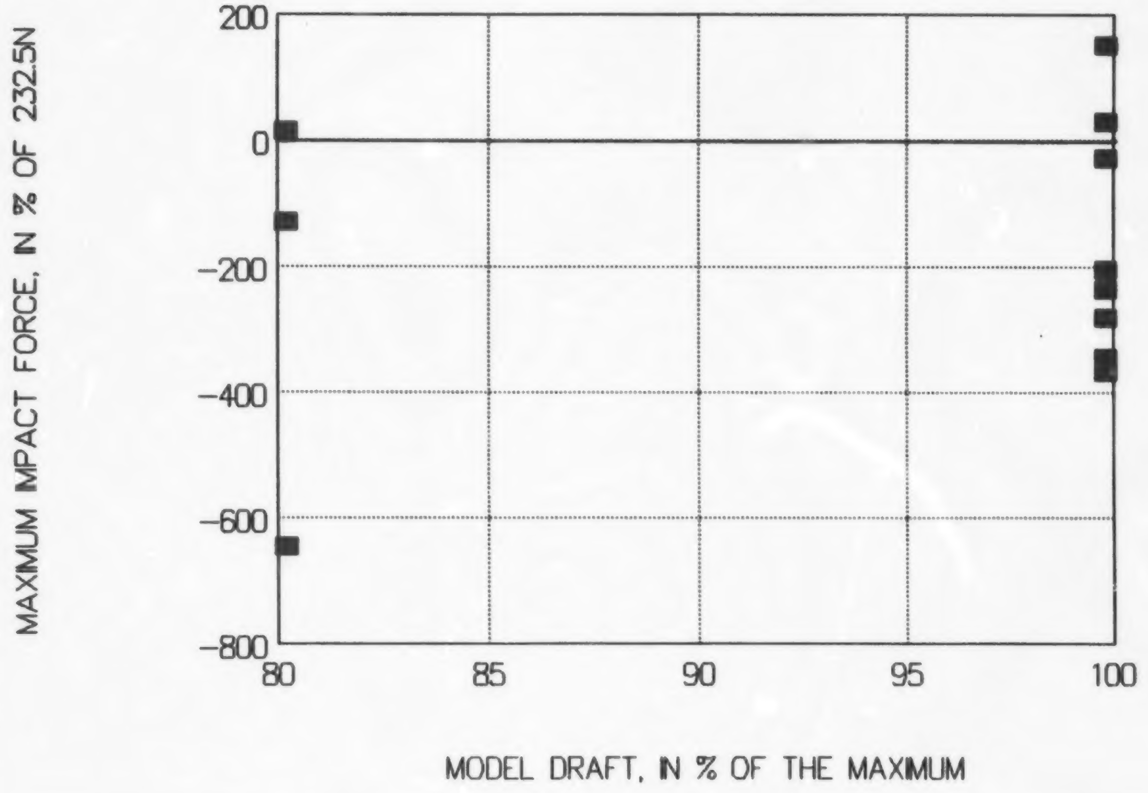
MAXIMUM IMPACT FORCES ON THE NOZZLE

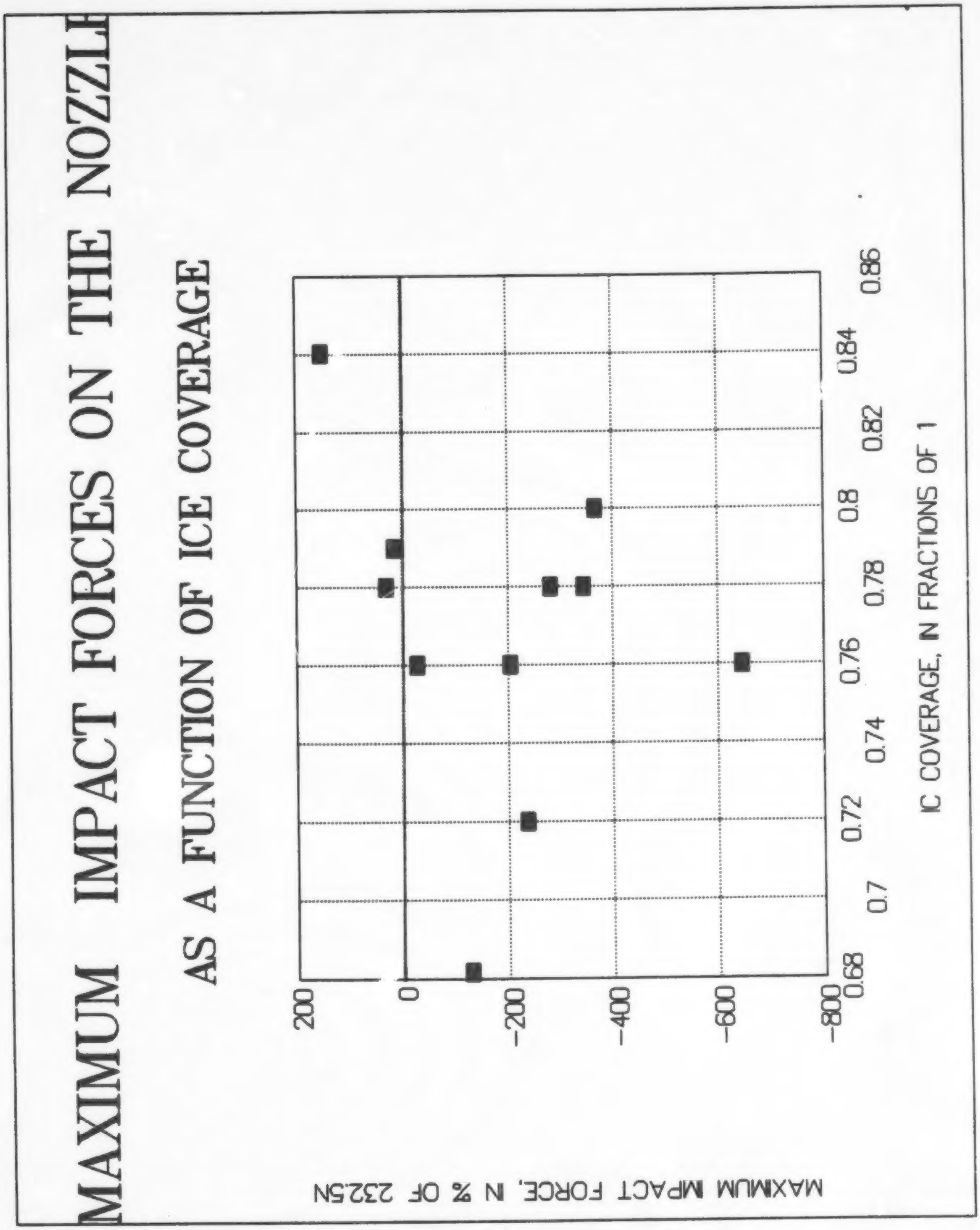
AS A FUNCTION OF MODEL SPEED

Figure 13.30

MAXIMUM IMPACT FORCES ON THE NOZZL

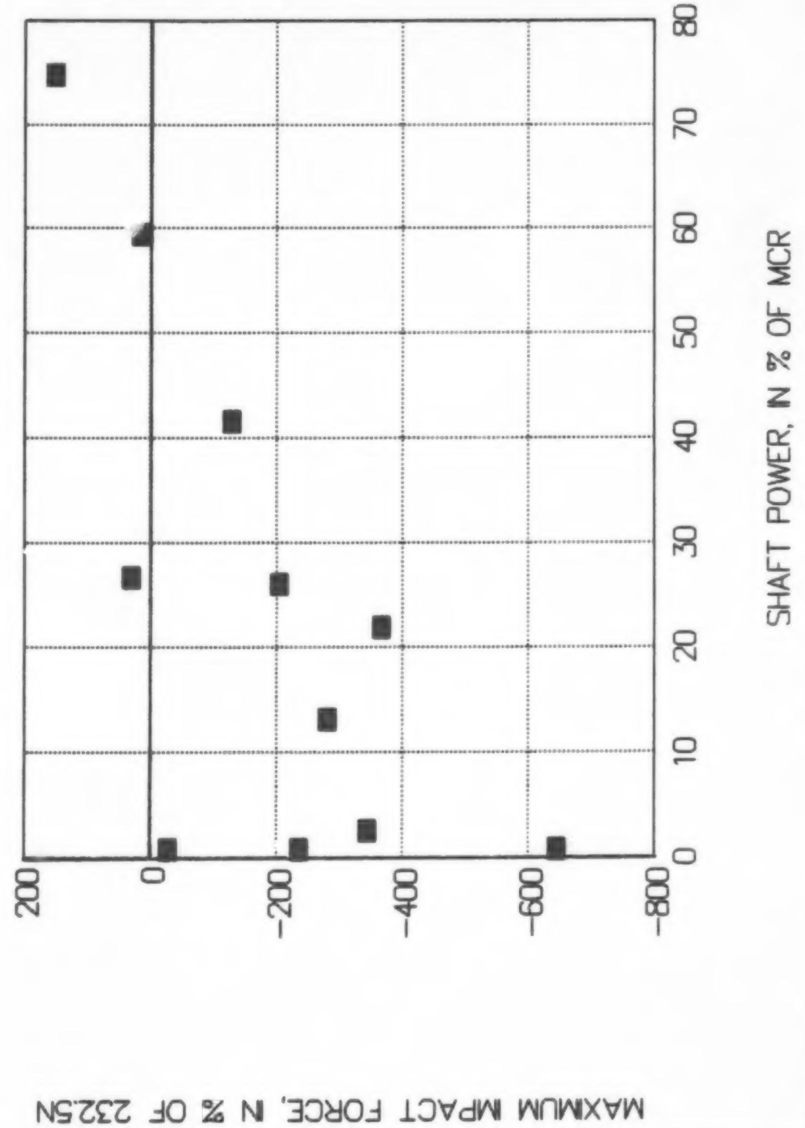
AS A FUNCTION OF MODEL DRAFT




MAXIMUM IMPACT FORCES ON THE NOZZLE
AS A FUNCTION OF ICE COVERAGE
MAXIMUM IMPACT FORCE, IN % OF 232.5N
200
0
-200
-400
-600
-800
0.68
0.7
0.72
0.74
0.76
0.78
0.8
0.82
0.84
0.86
IC COVERAGE, IN FRACTIONS OF 1

# MAXIMUM IMPACT FORCES ON THE NOZZL

## AS A FUNCTION OF CENTER SHAFT POWER



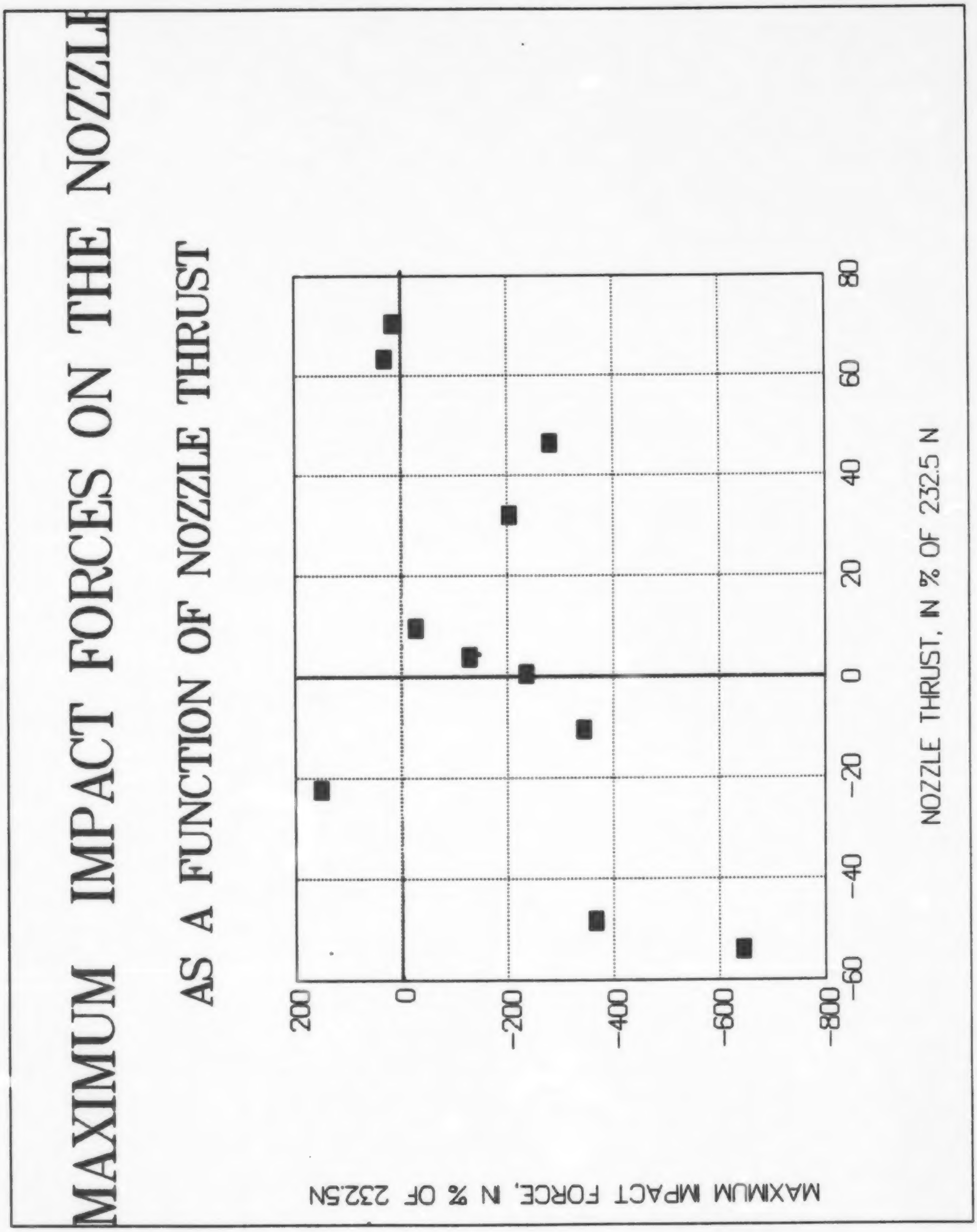
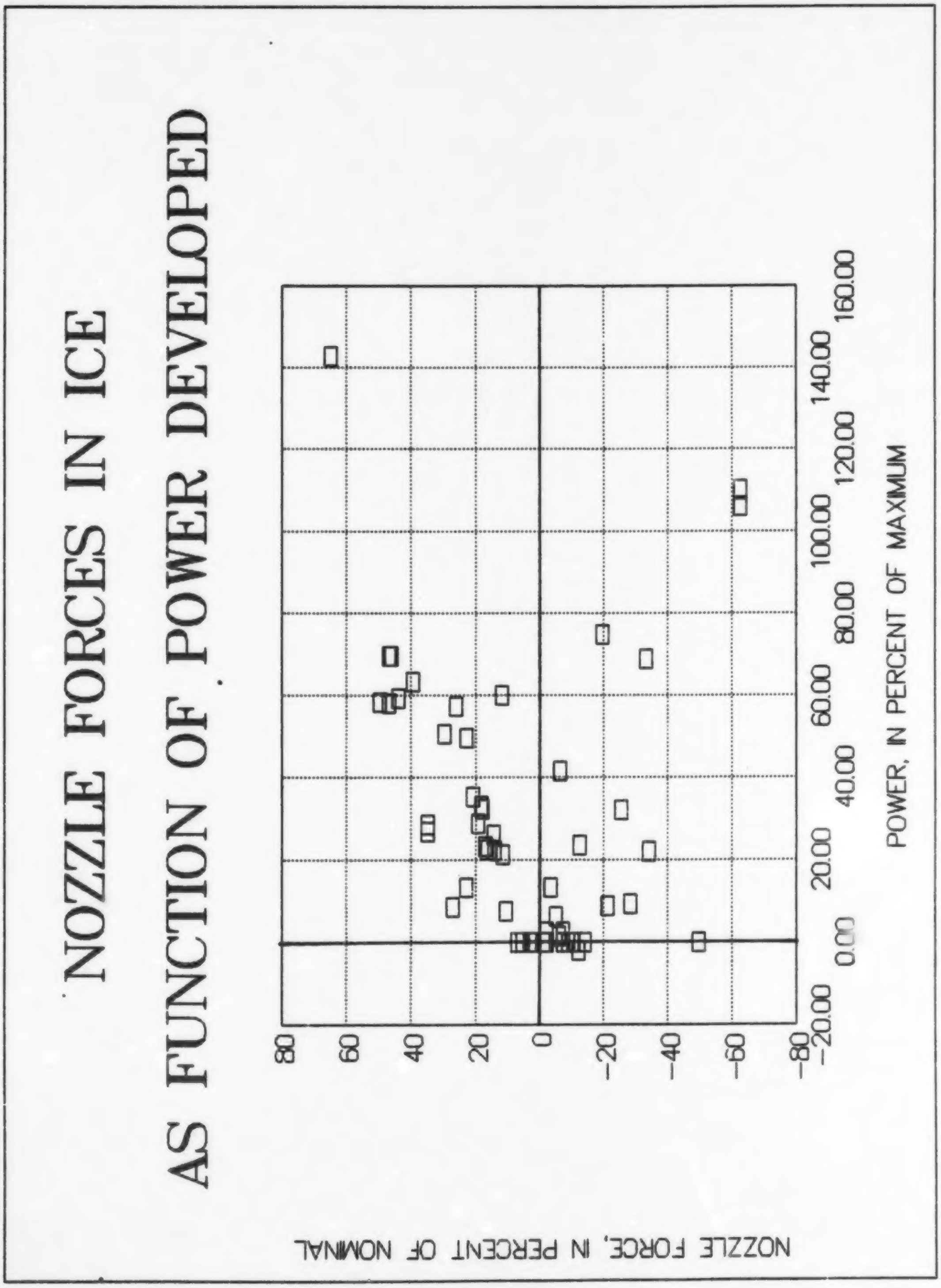

MAXIMUM IMPACT FORCES ON THE NOZZL
AS A FUNCTION OF NOZZLE THRUST
MAXIMUM IMPACT FORCE, IN % OF 232.5N
200
0
-200
-400
-600
-800
-60
-40
-20
0
20
40
60
80
NOZZLE THRUST, IN % OF 232.5 N

Figure 13.34



NOZZLE FORCES IN ICE AS FUNCTION OF POWER DEVELOPED

Figure 13.35

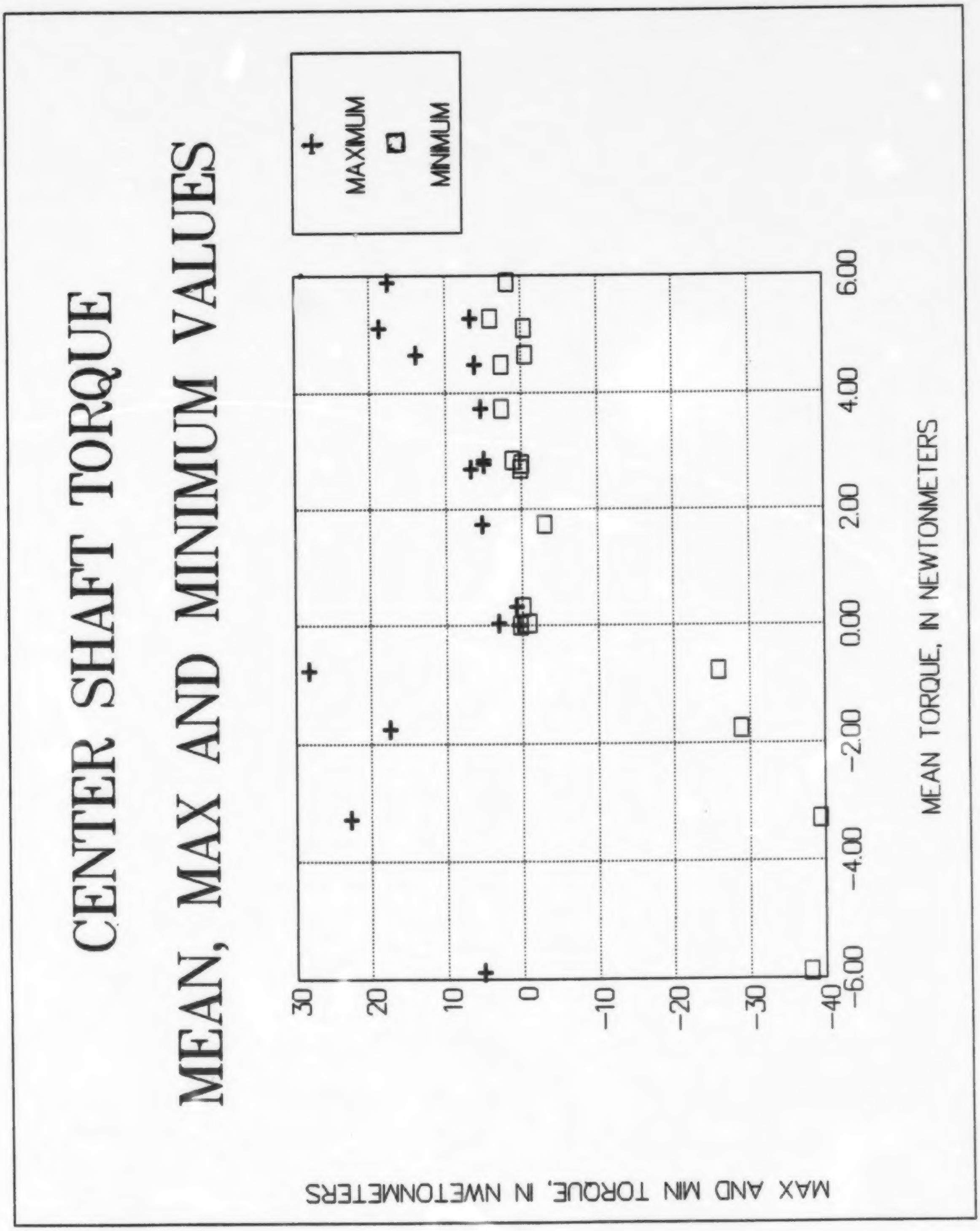
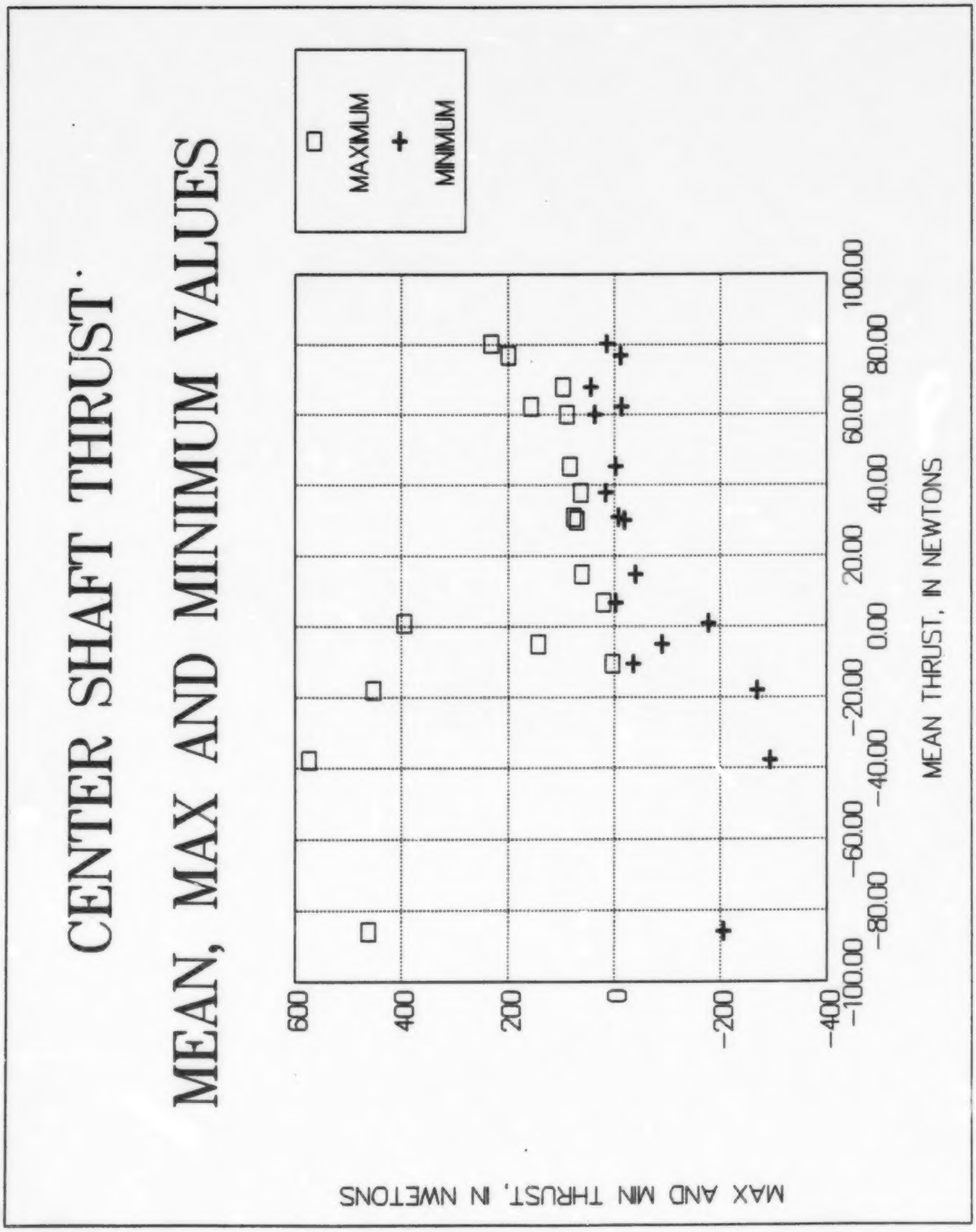

CENTER SHAFT TORQUE
MEAN, MAX AND MINIMUM VALUES
+ MAXMUM
□ MINIMUM
MAX AND MIN TORQUE, IN NWETONMETERS
MEAN TORQUE, IN NEWTONMETERS
30
20
10
0
−10
−20
−30
−40
−6.00
−4.00
−2.00
0.00
2.00
4.00
6.00

Figure 13.36


CENTER SHAFT THRUST
MEAN, MAX AND MINIMUM VALUES
MAXIMUM
MINIMUM
600
400
200
0
-200
-400
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
20.00
40.00
60.00
80.00
100.00
MEAN THRUST, IN NEWTONS
MAX AND MIN THRUST, IN NWETONS

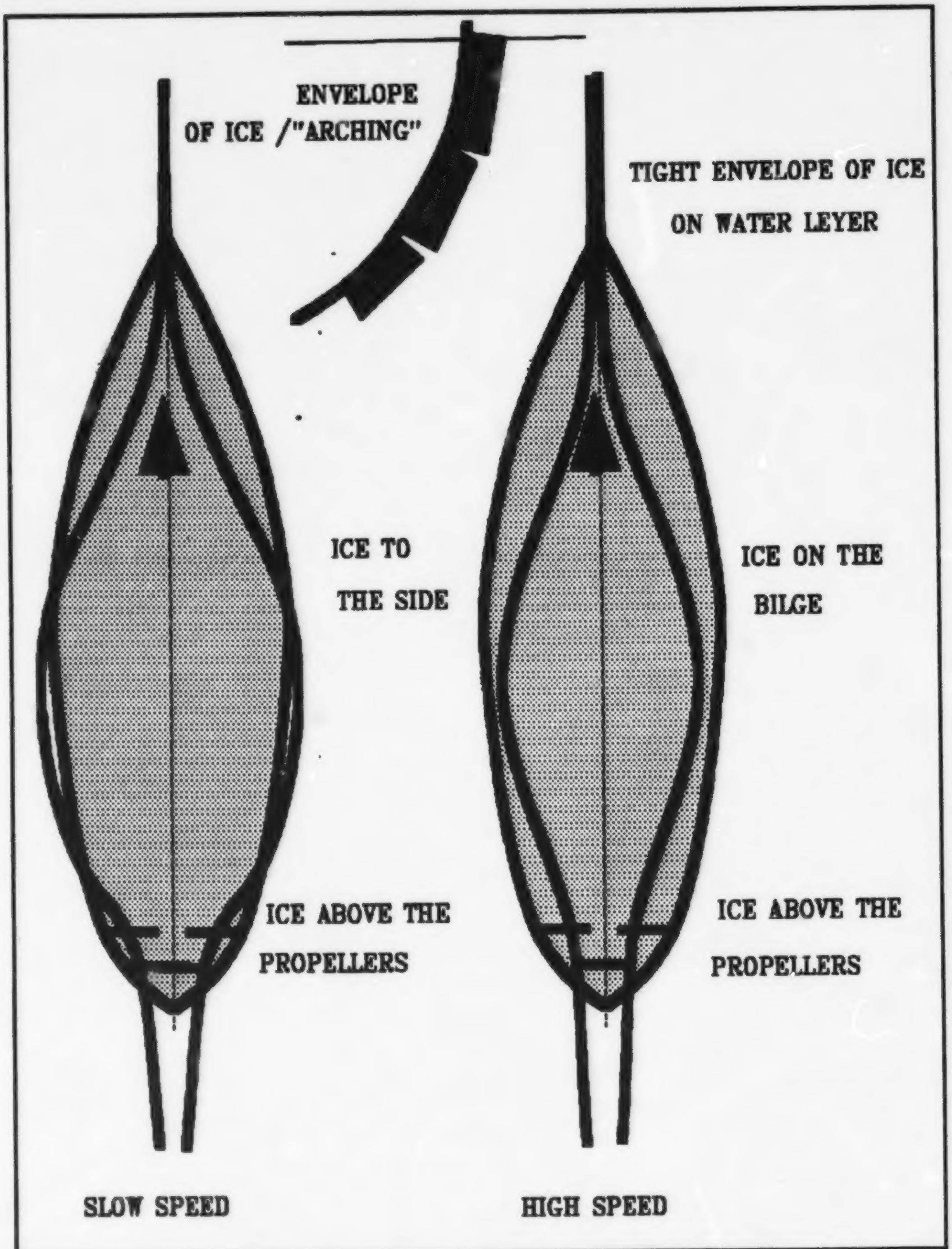
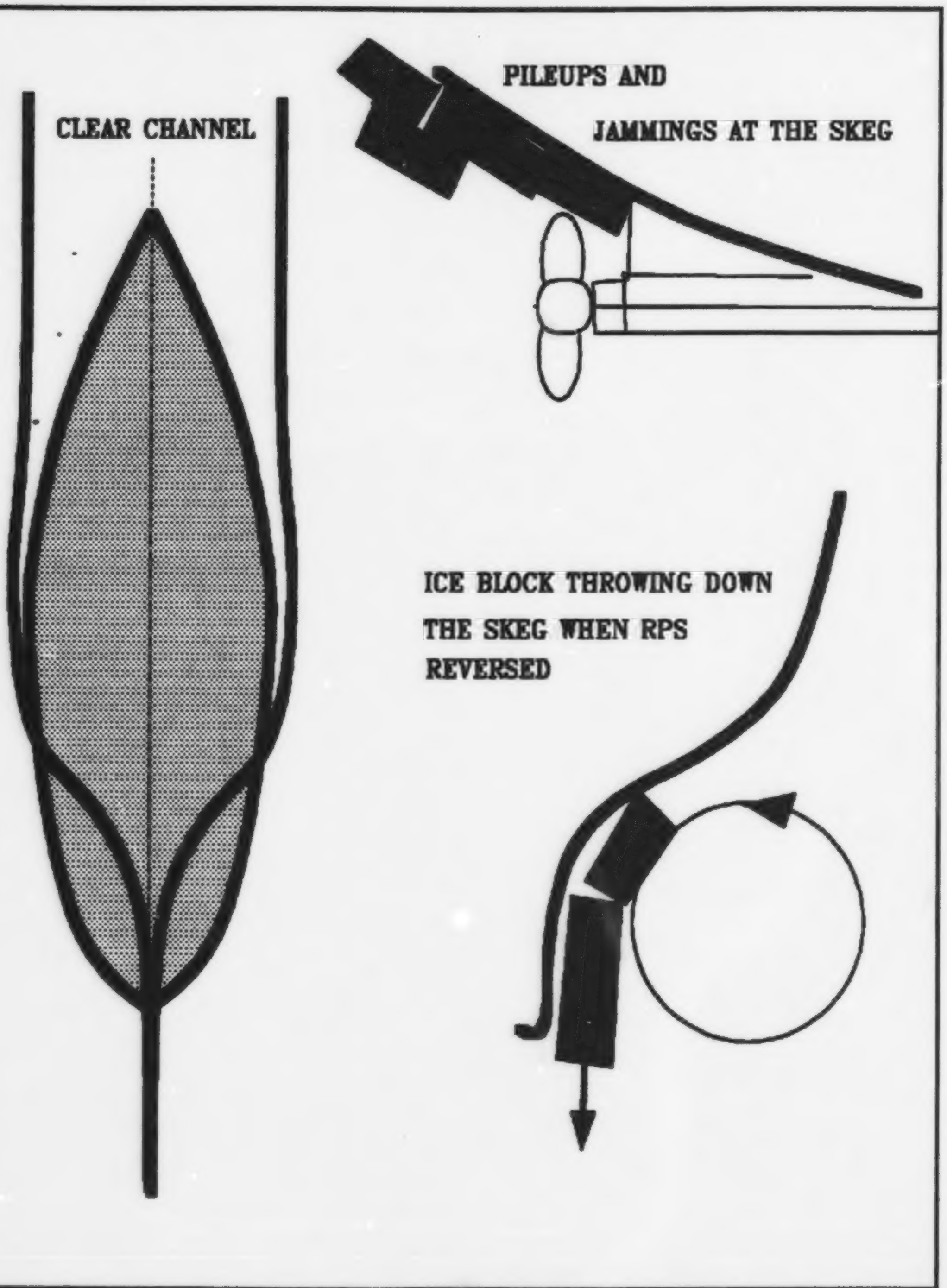


FIGURE TITLE: ICE FLOW UNDER THE HULL IN THE AHEAD MOTION

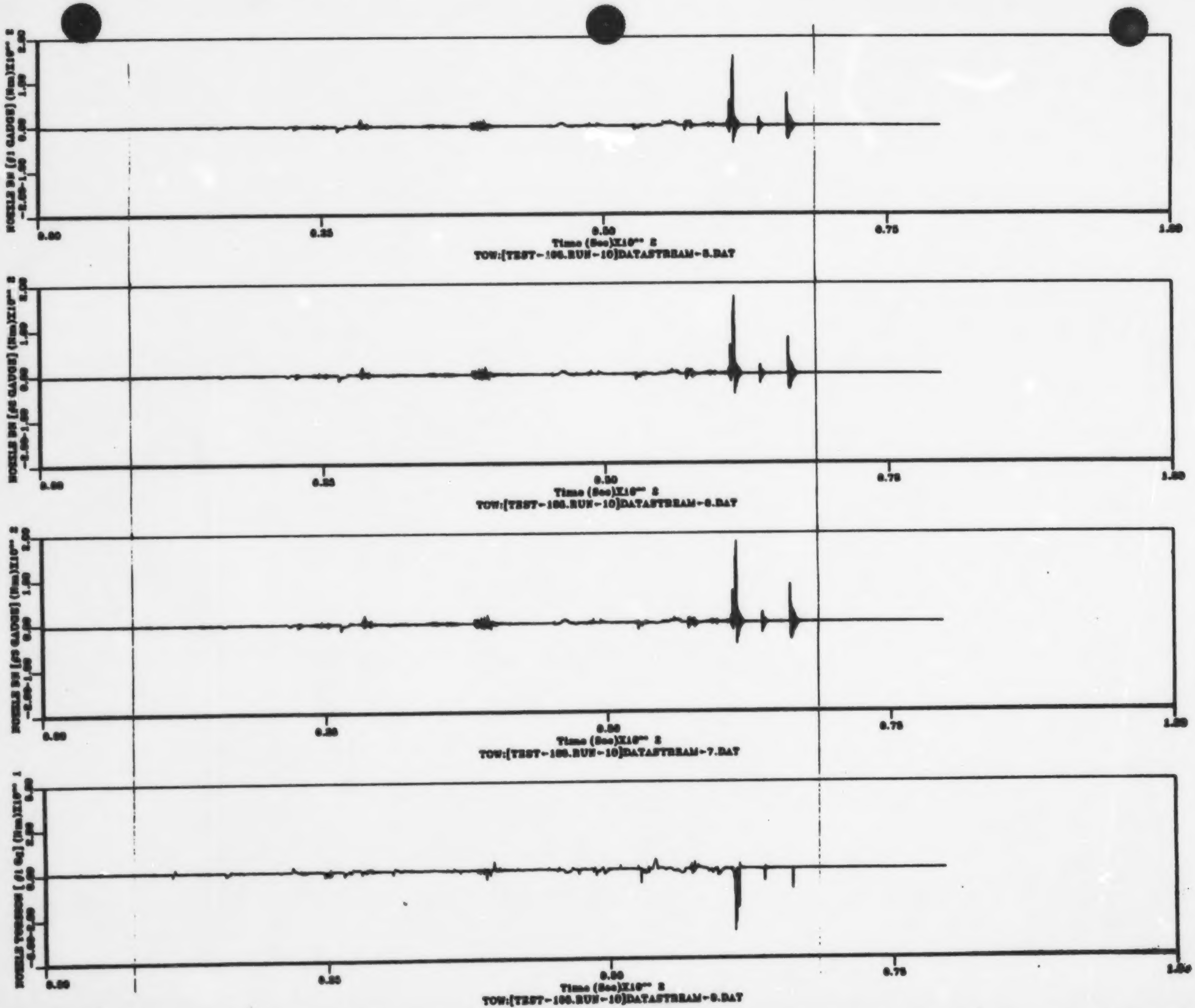
PROJECT NAME: ICE FLOW AND BLOCKAGE OF SHROUDED PROPELLERS

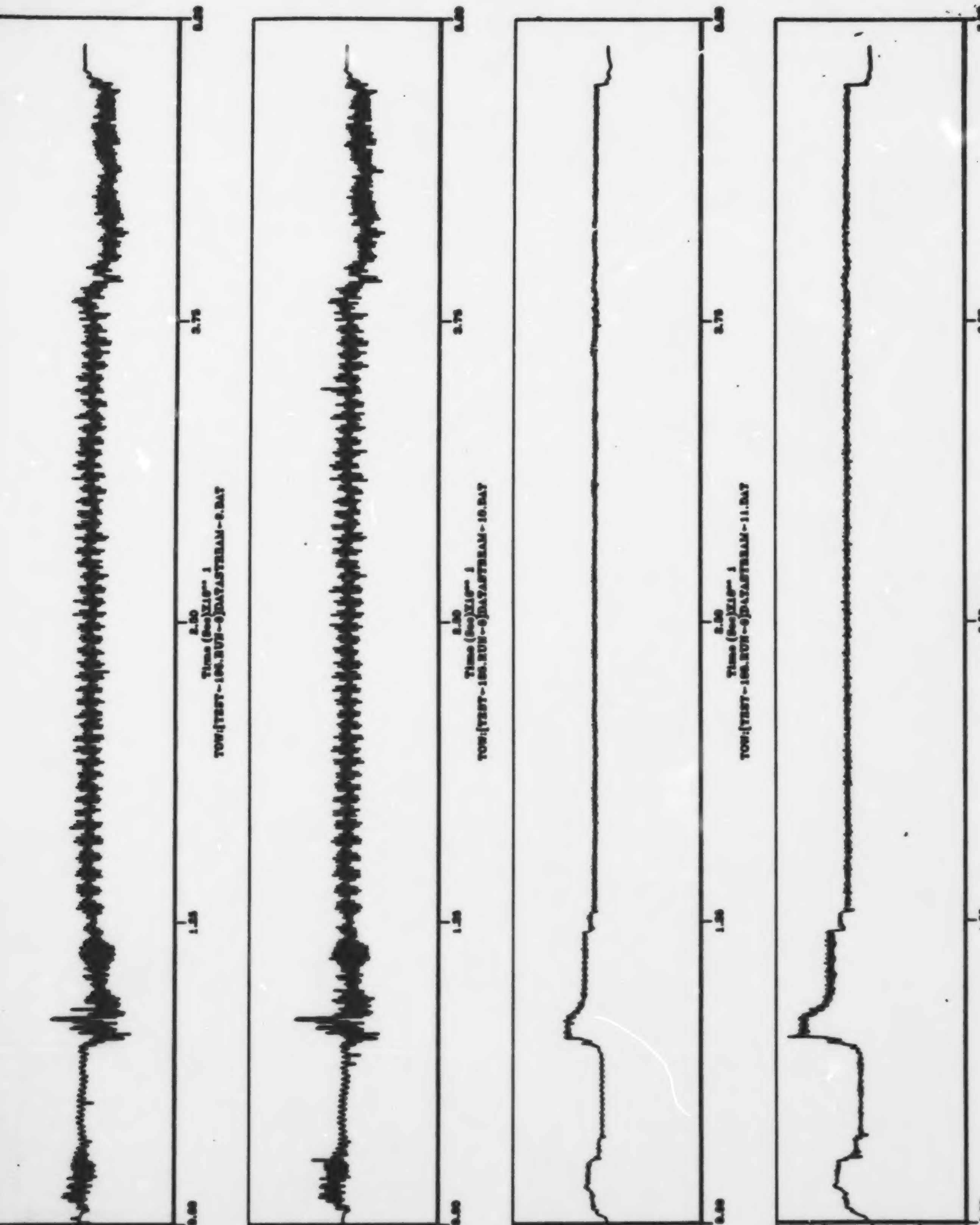
| | | | |
|---|---|---|---|
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: 13.37 |



|  |  |  |  |
|---|---|---|---|
| **FIGURE TITLE: ICE FLOW UNDER THE HULL IN THE ASTERN MOTION** | | | |
| **PROJECT NAME: ICE FLOW AND BLOCKAGE OF SHROUDED PROPELLERS** | | | |
| **DRAWN BY: VL** | **CHK'D BY: VL** | **SCALE: NONE** | **FIGURE NR:** 13.36 |

Figure 13.39


NOZZLE DN [#1 GAUGE] (N-m)X10** 2
-2.00 -1.00 0.00 1.00 2.00
0.00 0.25 0.50 0.75 1.00
Time (Sec)X10** 2
TOW:[TEST-108.RUN-10]DATASTREAM-5.DAT
NOZZLE DN [#2 GAUGE] (N-m)X10** 2
-2.00 -1.00 0.00 1.00 2.00
0.00 0.25 0.50 0.75 1.00
Time (Sec)X10** 2
TOW:[TEST-108.RUN-10]DATASTREAM-6.DAT
NOZZLE DN [#3 GAUGE] (N-m)X10** 2
-2.00 -1.00 0.00 1.00 2.00
0.00 0.25 0.50 0.75 1.00
Time (Sec)X10** 2
TOW:[TEST-108.RUN-10]DATASTREAM-7.DAT
NOZZLE TORSION [#1 Ga] (N-m)X10** 1
-5.00 -2.50 0.00 2.50 5.00
0.00 0.25 0.50 0.75 1.00
Time (Sec)X10** 2
TOW:[TEST-108.RUN-10]DATASTREAM-8.DAT


0.00
1.25
2.50
3.75
5.00
Time (Sec)X10^-1
TOW:[TEST-108.RUN-9]DATASTREAM-9.DAT
TOW:[TEST-108.RUN-9]DATASTREAM-10.DAT
TOW:[TEST-108.RUN-9]DATASTREAM-11.DAT
TOW:[TEST-108.R DATASTREAM-12.DAT
NOZZLE TORSION
CENTRE THRUST
CENTRE TORQUE

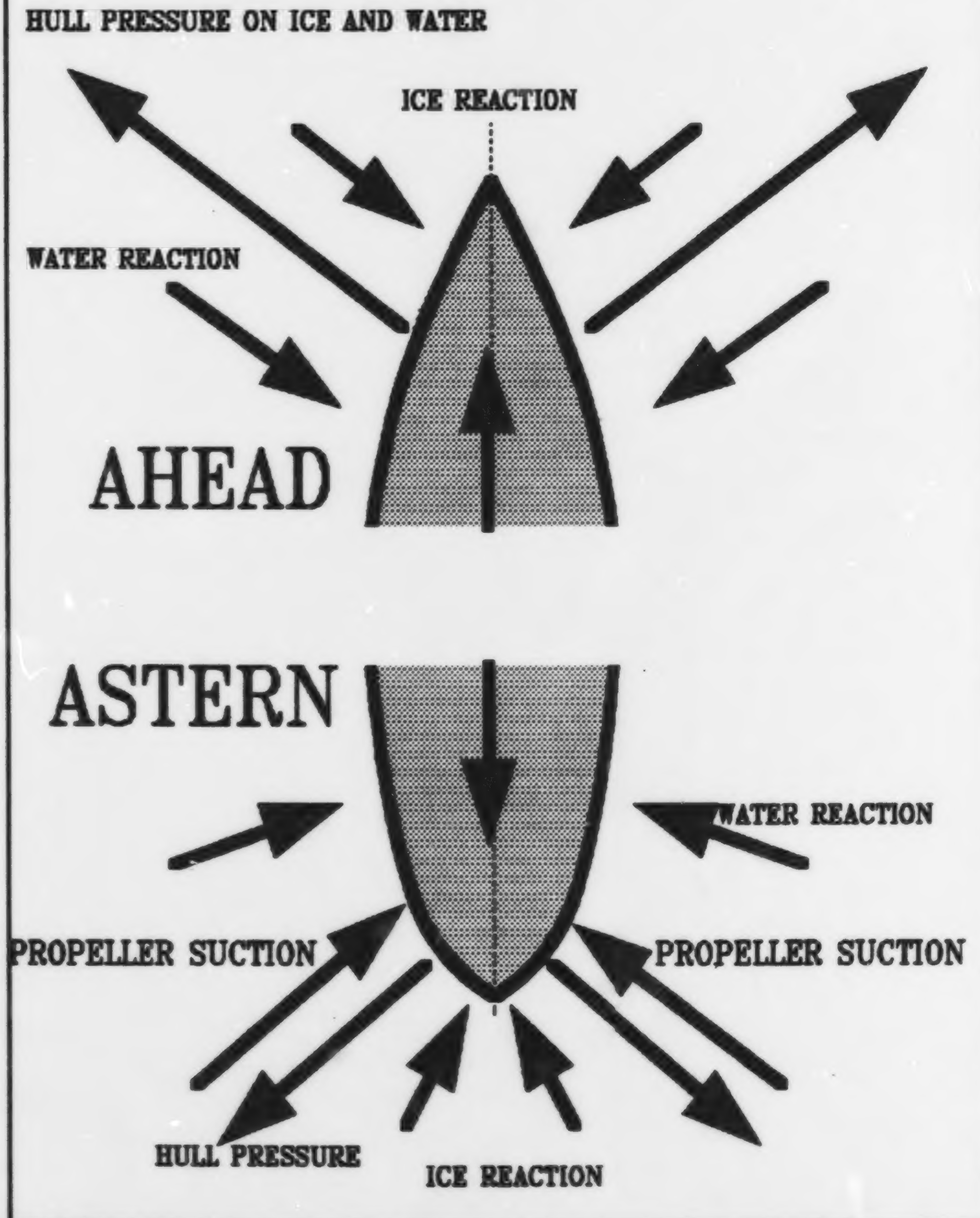


**FIGURE TITLE:** ICE/WATER/SHIP INTERACTION FORCES AHEAD AND STERN

**PROJECT NAME:** ICE FLOW AND BLOCKAGE OF SHROUDED PROPELLERS

| | | | |
|---|---|---|---|
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 13.41 |

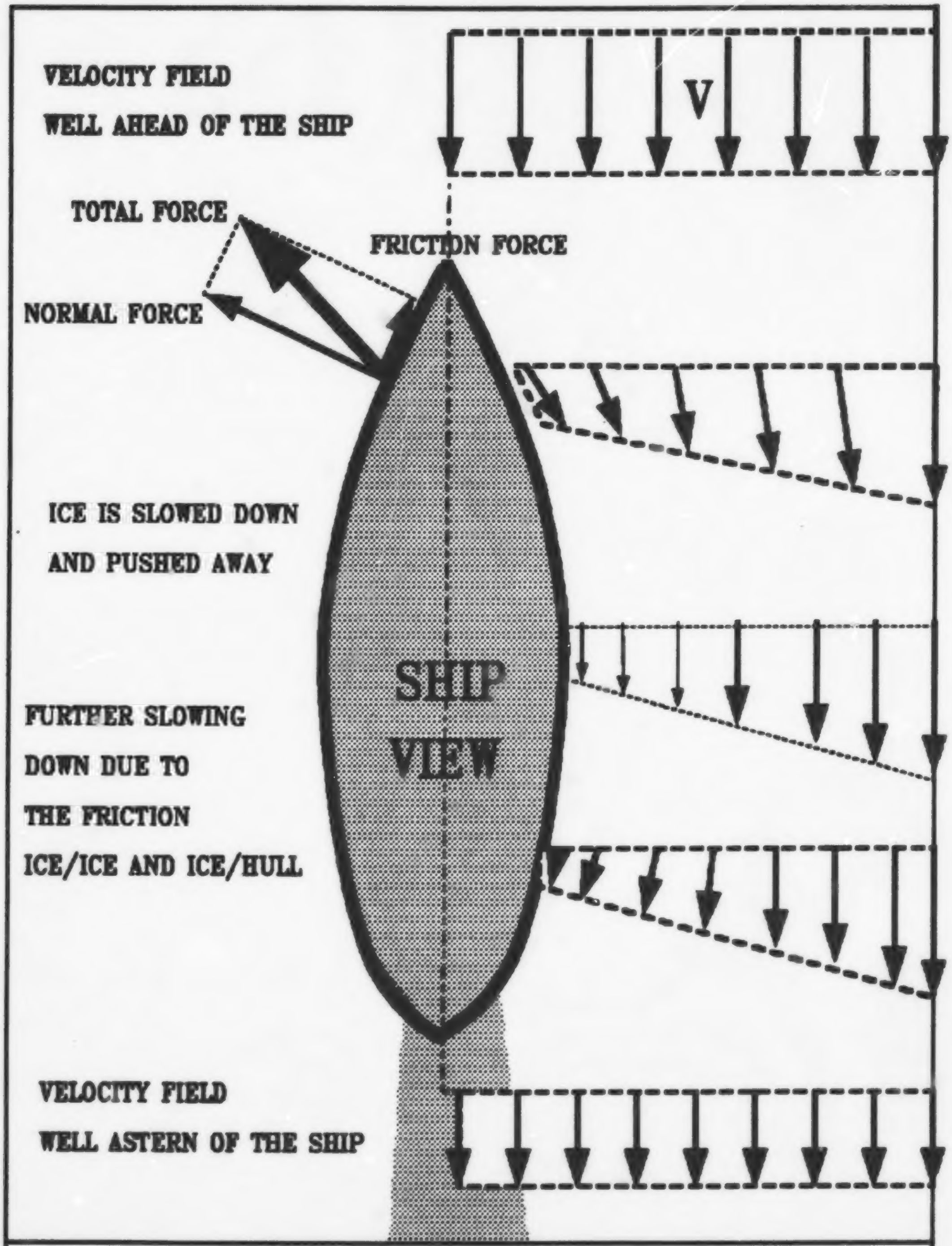


**FIGURE TITLE:** VELOCITY CHANGE IN BROKEN ICE FIELD/SHIP VIEW

**PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION

**DRAWN BY:** VL **CHK'D BY:** VL **SCALE:** NONE **FIGURE NR:** 13.42

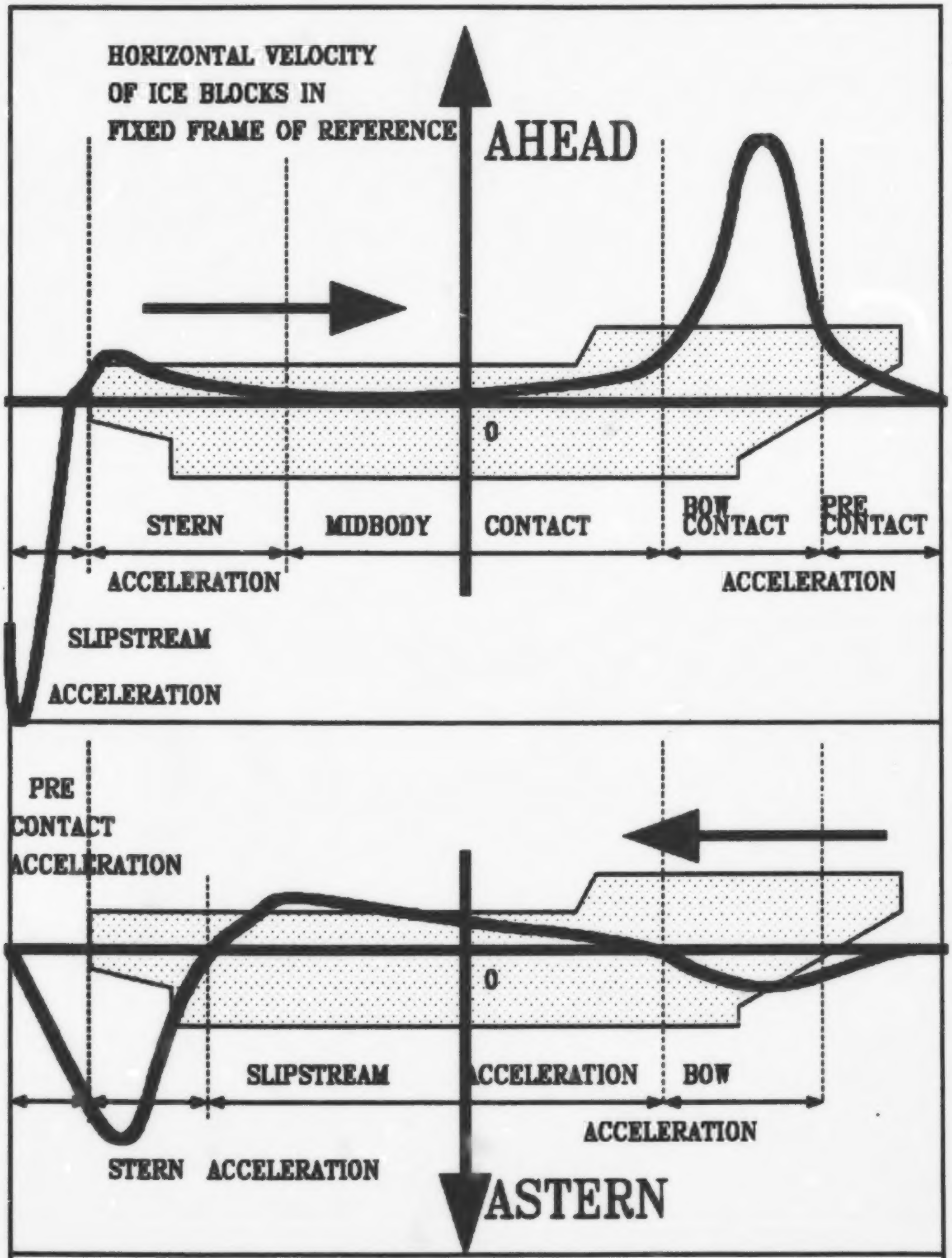
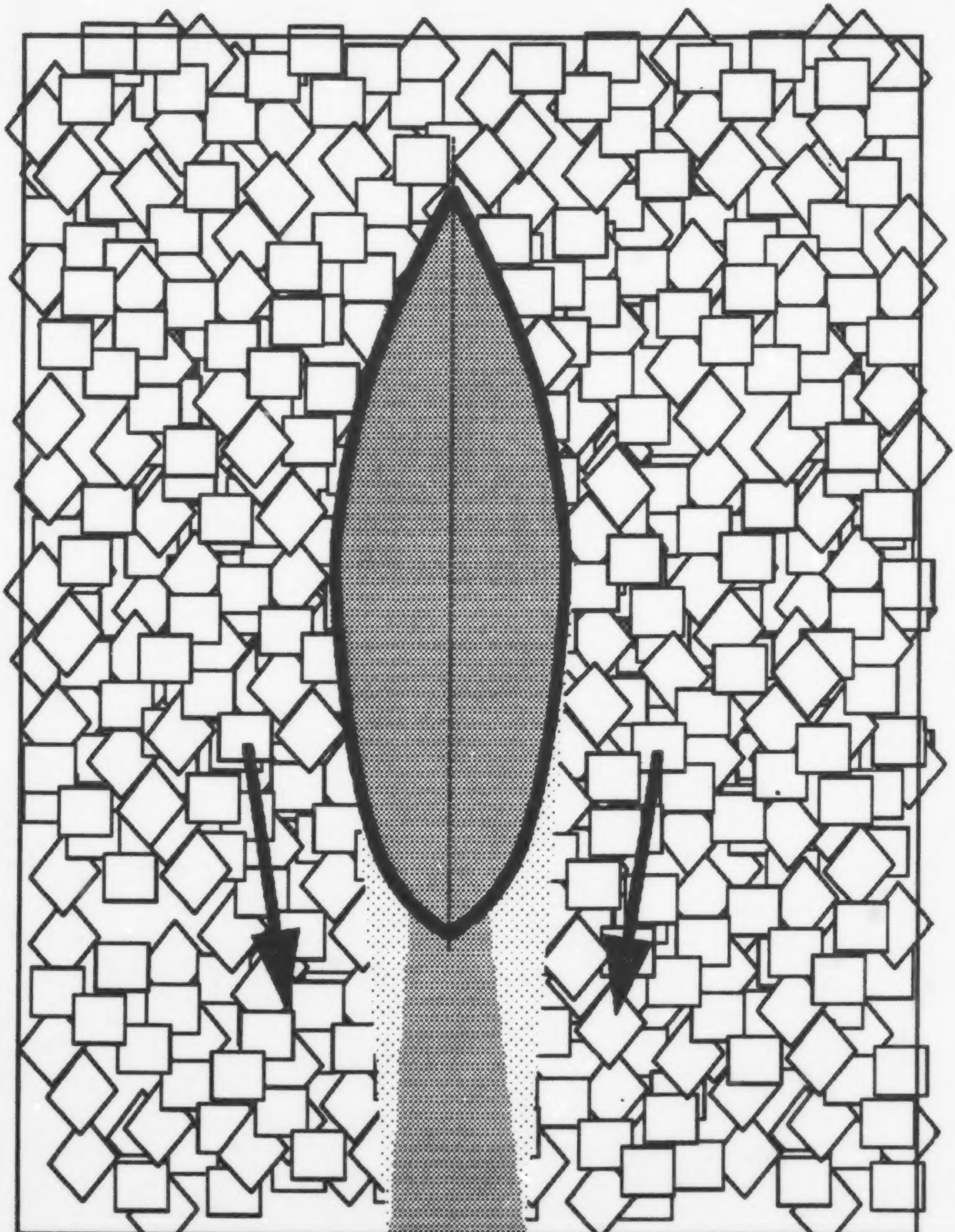


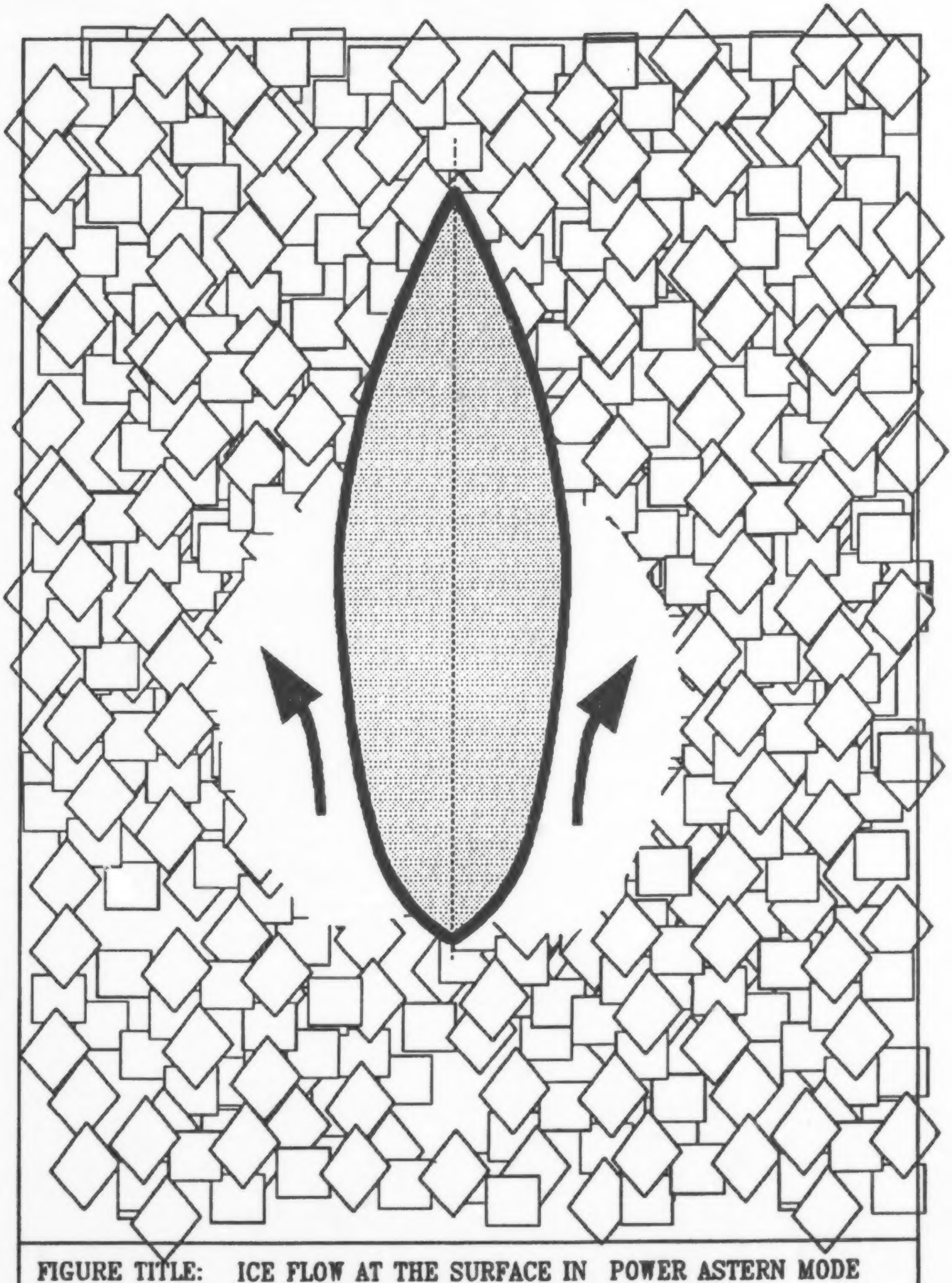
**FIGURE TITLE:** BLOCK VELOCITY DISTRIBUTION ALONG THE SHIP

**PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION OF SHROUDED P.

| | | | |
|---|---|---|---|
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: 13.43. |



| | | | |
|---|---|---|---|
| **FIGURE TITLE:** ICE FLOW AT THE SURFACE IN BOLLARD AHEAD MODE | | | |
| **PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION | | | |
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 13.44 |



| | | | |
|---|---|---|---|
| **FIGURE TITLE:** ICE FLOW AT THE SURFACE IN POWER ASTERN MODE | | | |
| **PROJECT NAME:** ICE FLOW AND BLOCKAGE INVESTIGATION | | | |
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 13.45 |

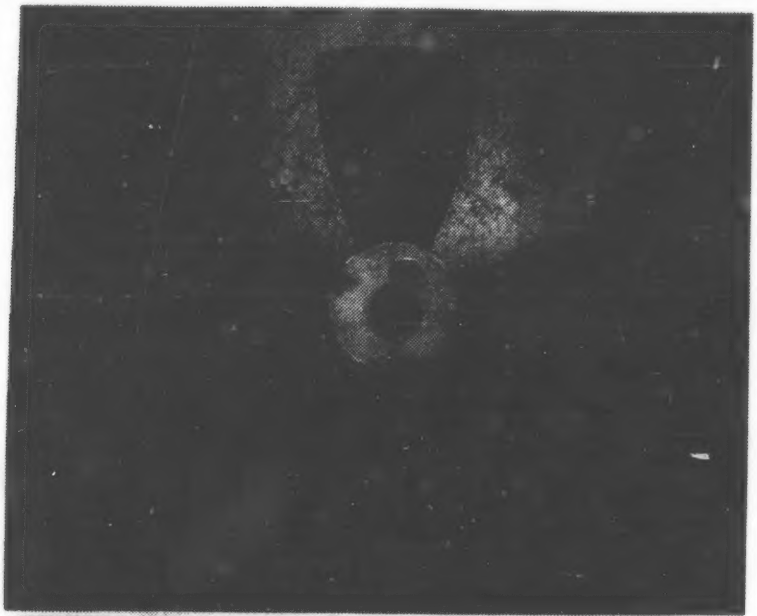


Photo 24-
Nozzled Propeller

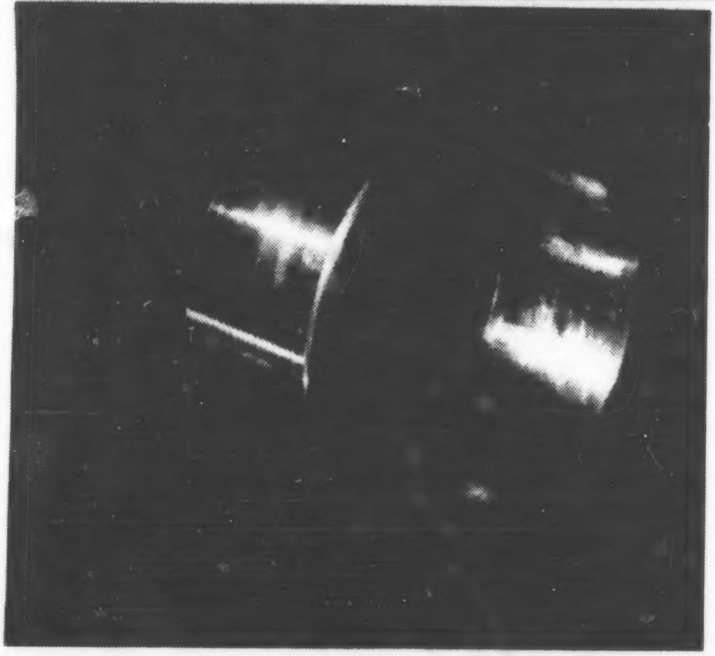


Photo 25-
Nozzle

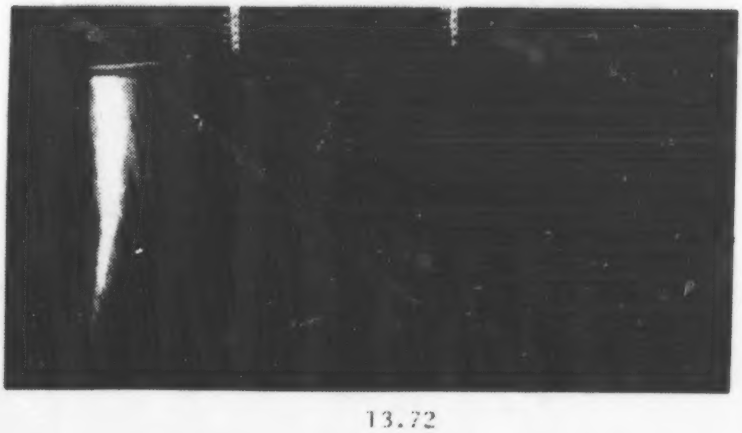


Photo 26-
Deflector

Photo 13.42 - Typical Broken Ice Field Condition

Photo 13.43 - Typical Broken Ice Field Condition

Photo 13.44 - Ship Entering the Corral

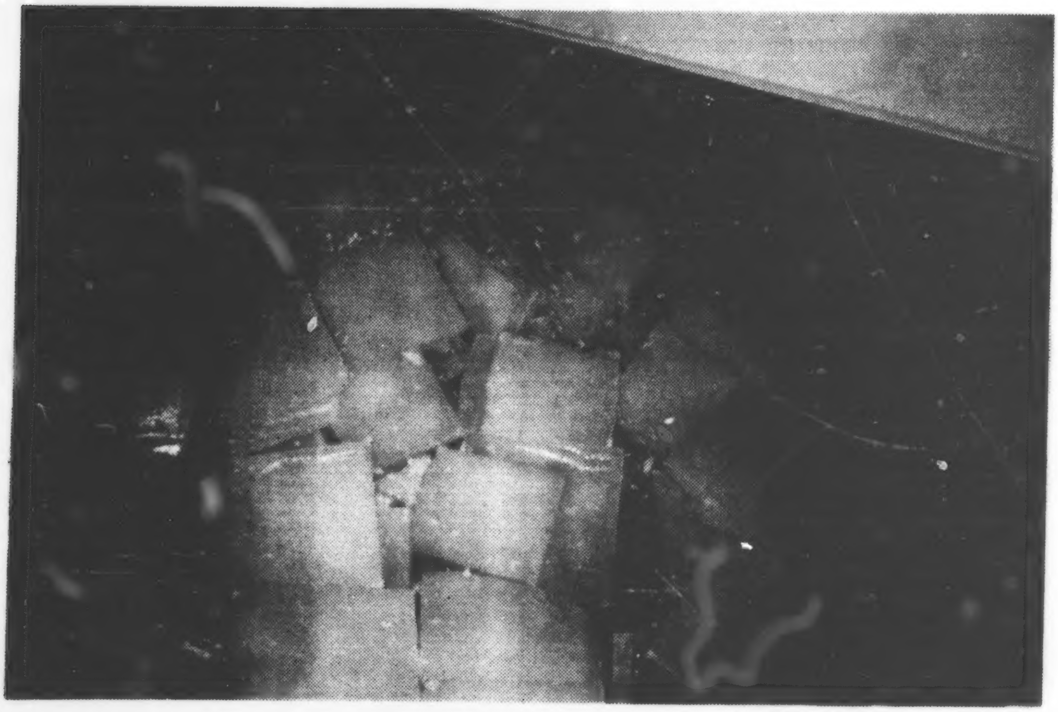


Photo 13.45 Jamming of Ice Blocks in Astern Motion

Photo 13.46 - Footprints of Propeller Interaction with Blocks

Photo 13.47 - Footprints of Propeller Interaction with Blocks

Photo 13.48 - Footprints of Propeller Interaction with Blocks

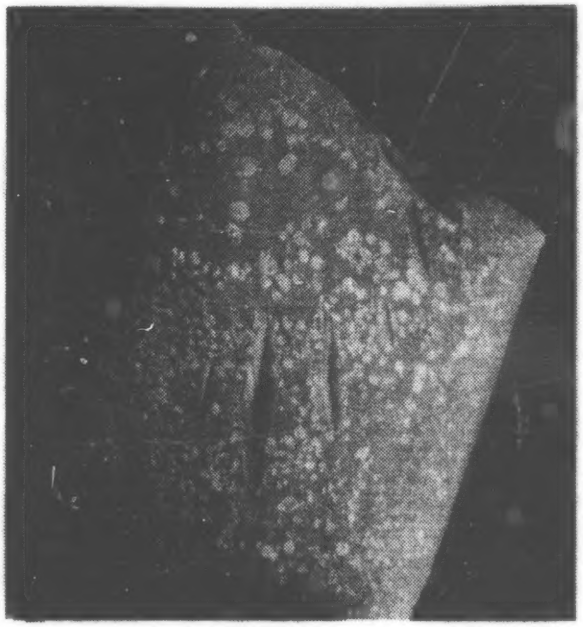


Photo 13.49 - Footprints of Propeller Interaction with Blocks

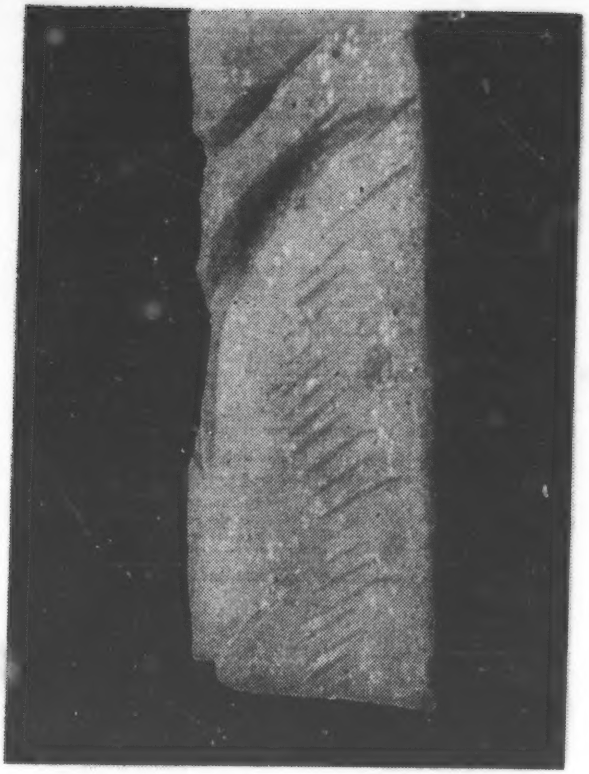


Photo 13.50 -Footprints of Propeller Interaction with Blocks

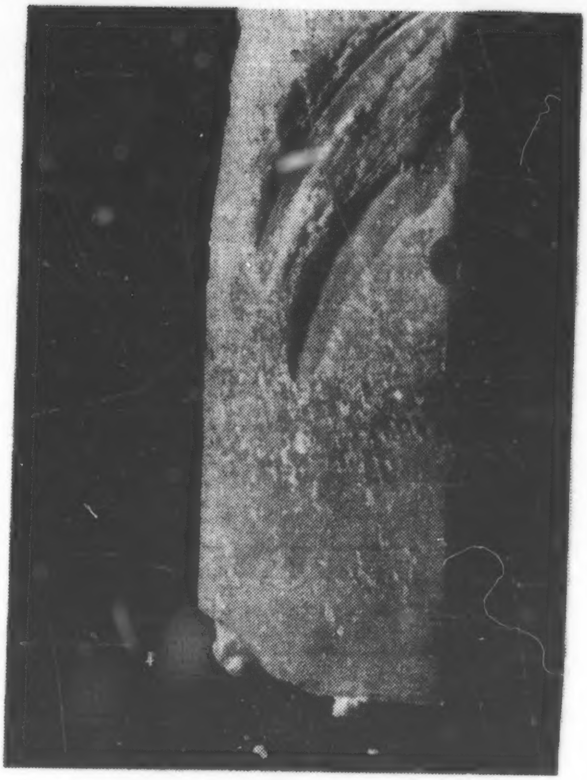


Photo 13.51 - Footprints of Propeller Interaction with Blocks

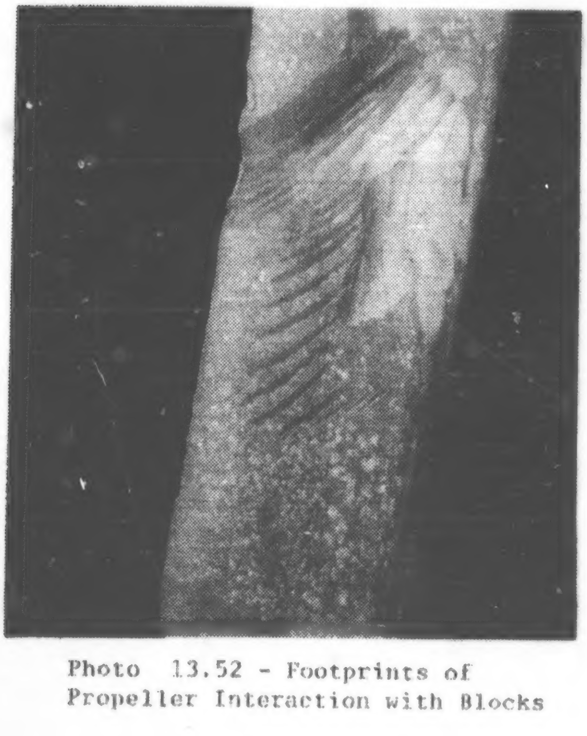


Photo 13.52 - Footprints of Propeller Interaction with Blocks

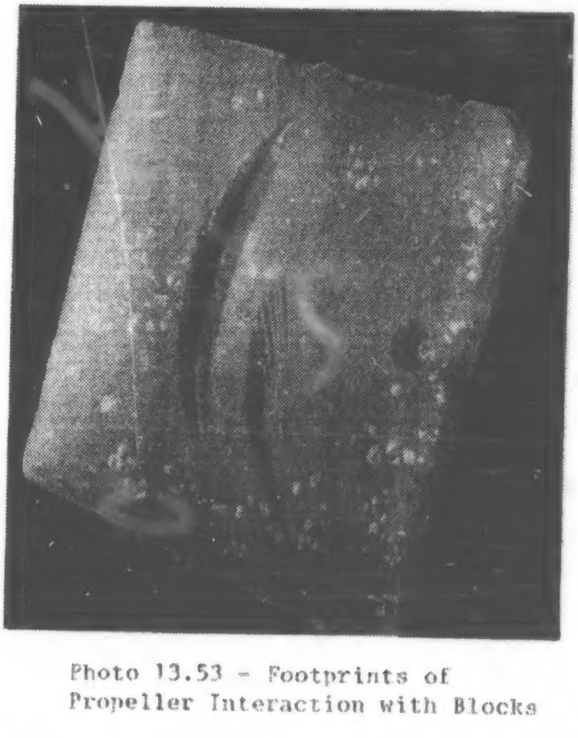


Photo 13.53 - Footprints of Propeller Interaction with Blocks

Photo 13.54 - Wax Tracings on Bow and Stern of Model

Photo 13.55 - Wax Tracings on Bow and Stern of Model

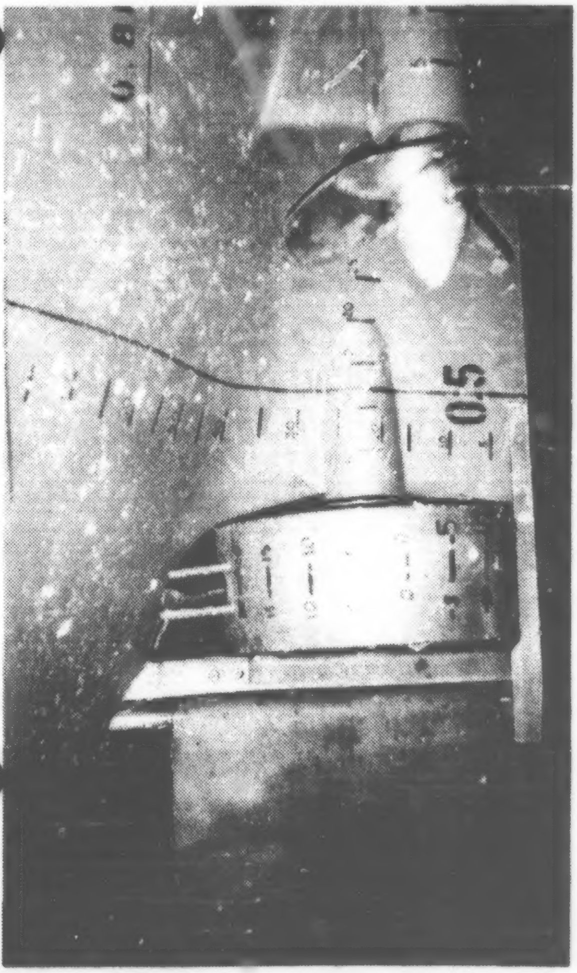


Photo 13.56 - Wax Tracings on Bow and Stern of Model

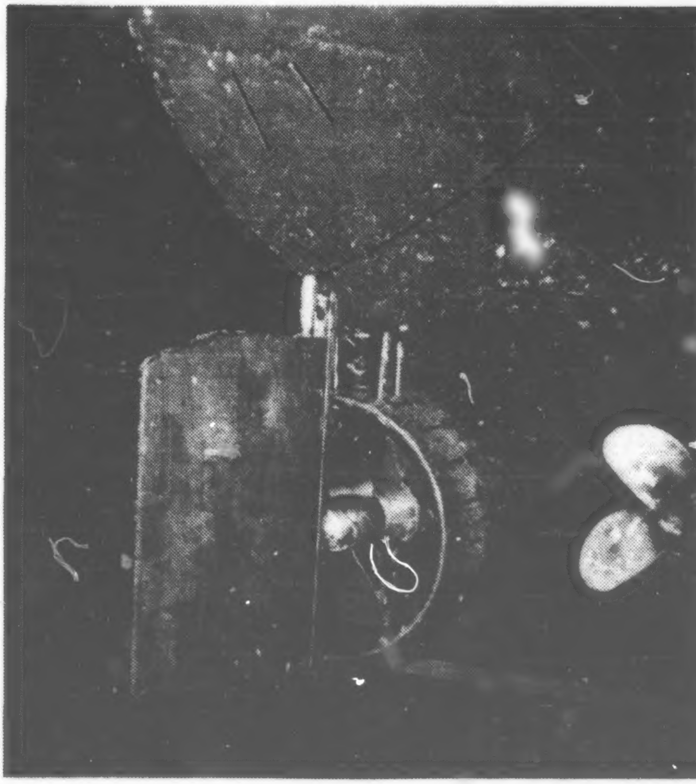


Photo 13.57 - Wax Tracings on Bow and Stern of Model

Photo 13.58 - Wax Tracings on Bow and Stern of Model

# *14. OVERLOAD TESTS WITH ICE DEFLECTOR - RESULTS*

## *14.1. Means of preventing and mitigating ice ingestion and blockages of nozzles.*

*A number of means exist for the prevention of ice ingestion into the nozzles. They can be classified as mechanical and non-mechanical. Among them:*

*Mechanical means of deflecting the flow of ice:*

*hull form design*
*ice islands/ skirts*
*appendages/fins/ deflectors*
*cages*
*stators*

*Non-mechanical (Medium induced flow of ice):*

*air bubbling*
*waterjets*

*Further, a number of designs exist which may alleviate the severity of the blockages of nozzles:*

*slots in the nozzle ring*
*protrusions on the nozzle mouth*
*air discharge into the nozzle*

*below, a brief description of these devices is given:*

### ***Hull form design***

*The selection of the main parameters of the hull design like draft, length, beam, the hull geometry angles has an influence on the amount of ice interacting with a shroud and propellers. In particular the design of the stern area, selection of number of shafts, rudders and the length of the stern and submergence of the propellers influences the amount of ice in the nozzle. As the ship hull form was given for this particular project, no modifications to the hull design were contemplated.*

### ***Ice islands/ skirts***

*These can be best described as the "plows" guiding and deflecting the ice mass away from the propellers and nozzles. As ice follows closely the water flow pattern, the success of such designs is limited.*

### ***Appendages/fins/deflectors.***

*A number of designs and applications exist having in purpose the* *deflection of individual ice blocks away from the immediate proximity of the propellers and nozzles while letting water pass with little disturbance. A number of such appendages vary from one to three on each side of the propeller.*

**Cages**

*A number of designs were proposed (Reference 14) which, in effect, provided a complete cage surrounding the propeller disk area thus "sieving" water flowing into the propellers. Such designs are complex and their reliability unproven.*

**Stators.**

*Nozzle with a fore or aft stator offers some advantages*

*extra strength and*
*hydrodynamic efficiency.*

*Its efficiency as an ice deflector however is not certain, as much ice would "sit" on the cage instead of going thru the nozzle.*

**Waterjets**

*Water jets were tried as a mean of ice deflecting and as a channel cleaning device with some success (Reference 15). This test series has shown that the waterjet can be considered as a candidate for the ice block deflection. Waterjets offer the advantage of not interfering with the hydrodynamic ship performance in lengthy open water transits.*

**Air bubbling**

*Air bubbling generates a secondary water stream which washes the hull thus altering ice flow patterns into the propellers. A number of ships are equipped with this type of system. Lately (Reference 16) a direct injection of air into the propeller disk was shown to alleviate the severity of ice/ propeller interaction.*

**Slots in the nozzle ring**

*Reference 11 describe the application of the slotted nozzle in ice. Such a feature offers the relief of the severity of the nozzle blockages and may lead to the improved efficiency in certain conditions. Clogging of the slots with ice and lowering of the strength of the nozzle assembly are the disadvantages.*

**Protrusion on the nozzle mouth**

*A number of different concepts are available:*

- *spikes*
- *blisters*

*They are designed to destabilize the ice blocks "sitting" on the nozzle mouth during the blockage. This may lead to the complete disengagement of an ice block and a nozzle or to the creation of water bypass into the nozzle during the blockage, which reduces its severity. One of the options is shown in Figure 14.1.*

**Air discharge into the nozzle**

*Air discharge leads to the lowering of the ice torque in the clogged or blocked condition, thus relieving propeller in its work. No data is available on this topic at this time other than the patentholders'claims.*

## *14.2. Design of the ice deflector*

*A triple screw configuration with the shroud on the centerline shaft has the following consequences in terms of the blockage:*

### Ahead condition

1. *Centerline skeg divides the nozzle mouth into two parts, limiting the area available for ice to "sit" on.*
2. *Wing propellers mill incoming ice before it can reach the nozzle.*
3. *Wing propellers provide a powerful slipstream effectively preventing large blocks of ice from overhanging on the nozzle mouth.*
4. *The centerline nozzle/propeller system absorbs only about 1/3 of the power delivered, hence their ice suction capability is limited (see Chapter 11).*

### Astern condition

1. *Centerline rudder effectively divides the nozzle ring into two halves (see comment #1 above).*
2. *Aft stern area of the triple shaft centerline rudder icebreaker is narrower than the corresponding part of the twin shaft twin rudder (for the same power delivered). This limits the amount of ice being submerged astern of the rudder.*
3. *Suction field in the astern mode of operations from all three propellers prevents ice from being pushed aside, and helps it to enter the propeller/nozzle intake area.*

*This test series has demonstrated that ice/nozzle interaction of the triple shaft icebreaker is much more severe in the astern mode of operation than in the ahead one. However, in the operations of CCG fleet, it is the ahead mode of operation which is of concern to the operators, as the leading icebreaker can not be suddenly slowed down as a result of the blockage. The following ship may not have enough time or space to accommodate such a change. For this reason the ahead blockage possibility was of the greatest concern.*

*The following means of mitigating the possibility of the ahead blockage were contemplated for this particular project:*

*deflectors/ fins,*
*nozzle mouth blisters and*
*waterjets*

*The blisters of the type shown in the preceding paragraph were thought to mitigate the blockage already in progress, that is to destabilize the ice block already being sucked into the nozzle mouth.*

*The possibility of using the waterjets in the ahead and astern operations was investigated during the course of this project. See Chapter 8 about the first step of the investigation.*

*Thus the only other preventive mean available was a deflector mounted in front of the nozzle mouth.*

*Such a deflector divides the nozzle mouth perimeter into four quarters, effectively limiting the amount of available space for ice block to adhere to.*

*A properly designed deflector can also offer some hydrodynamic advantages, like the improvement of water inflow angle into the propellers.*

*The best position of such a deflector would be at 10 o'clock position. However, due to the nature of the model, the only available means of the deflector attachment was to the wooden centerline shaft bossing (9 o'clock position).*

*The design of the deflector is shown in Figure 14.2. Detailed drawing of the streamlined section is given in the Appendix L. The cross section and the attachment of the deflector to the hull decide on the strength of the deflector which is very design - specific.*

*Only one side application was needed to assess its performance.*

*Photograph 14.21 shows the deflector manufactured of hard wood, for the purpose of the tests.*

## 14.3. Overload test results

### Tests purpose

The hydrodynamic performance of the deflector was thought to be difficult to assess within the constraints of this project. As stated earlier, a properly designed deflector can offer some hydrodynamic advantages. Therefore this test series served as a reference base to the forthcoming tests in ice rather than a verification of the hydrodynamic merits of the simplified deflector.

### Tests setup

The setup was analogous to that specified earlier (see Chapter 9) on the tests series 193.

### Tests results.

Table 14.1 summarizes the overload tests results of this series.

Forty tests were performed. The variables were the same as during the tests series 194:

ship speed, and

power level

Figures 14.3 to 14.10 show the results graphically.

The results should be used for comparison with the results of ice tests only.

The following observations are made:

1. In the bollard ahead condition, the propeller and the nozzle develop 232.5 N thrust, which translate into the thrust/ power ratio of 11.4 kG/HP, which is some 30% higher than the ratio for an open propeller.
2. At 15 knots speed, nozzle still develops a positive thrust, in spite of the reduced power.
3. In the bollard astern condition, propeller and nozzle develop approximately 85% of the thrust in the bollard ahead condition.
4. At 6 knots astern, the propeller and nozzle still develop 70% of the ahead bollard thrust.

**Comparison of the overload test results with and without the deflector.**

*Figures 14.11 to 14.14 show the comparison of the propulsor efficacy values with and without the deflector for the selected conditions tested. The efficacies are expressed in the percents of the nominal bollard efficacy of 11.4 KG/HP (full scale) or 0.59 N/W (model scale).*

*The following observations are made:*

1. *For the bollard ahead condition, the efficacy of the system is not affected by the installation of the deflector at 100% RPS. As RPS goes down, however, the efficacy of the system with deflector remains essentially unchanged, while that of the system without the deflector grows rapidly.*
2. *For the 10 knots ahead condition, there is a substantial difference (50%) between the efficacy with and without the deflector. Again, this efficacy difference decreases significantly with increase of RPS, and at 100% RPS there is no difference between the two values.*
3. *At bollard astern condition, a large difference is apparent at low RPS, narrowing somewhat at 100% RPS and above.*
4. *At six knots astern, the same observation as above is valid. Approximately 20% lowering of the efficacy value takes place due to the installation of the deflector at 100% RPS.*

*The reasons for the lowering of the gap between the two installations' efficacies at full RPS are most probably the facts that at the full power:*

1. *The nozzle draws water from everywhere around it, while for the low power, the suction comes from the ahead of the nozzle mainly. The space immediately ahead of the nozzle is affected by the deflector to a greater degree than the space around the nozzle.*
2. *At full power, the velocity of water inflow is largely governed by the rotational velocity of the propeller and not so much by the axial velocity of the water ahead of it.*

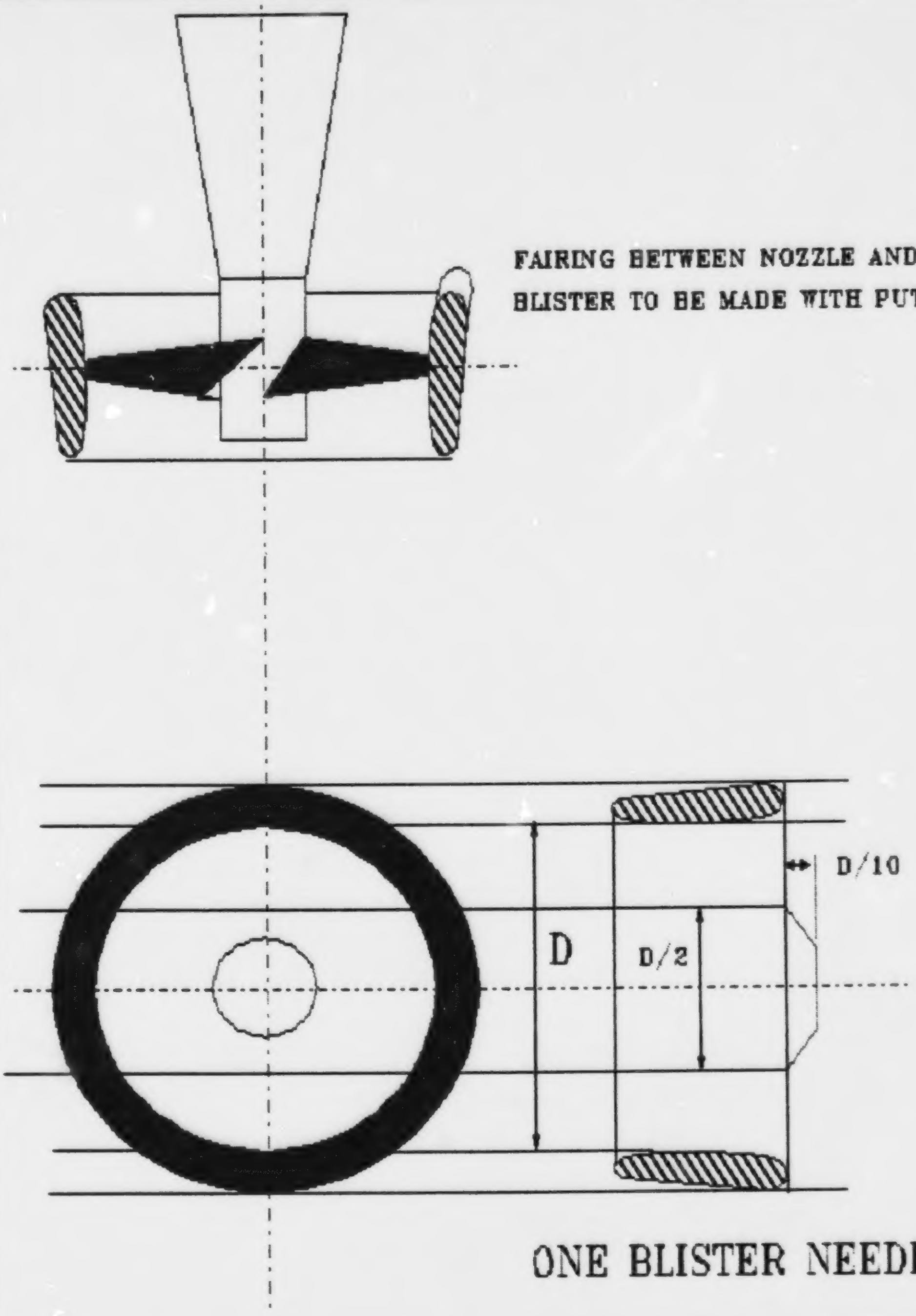
*It should be emphasized that the tests with and without the deflectors were done in two separate periods of time, the accuracy of the measurements in this series was not very high and that the positioning of the deflector was dictated by its strength of the attachment to the model considerations, not by*

*its hydrodynamic performance.*
*However, one should expect some lowering of the propulsor's efficacy due to the installation of the deflector simply due to the fact that the deflector can not be optimized for all of the operating conditions of the icebreakers (near bollard in ice/ high speed in open water). Further, the full scale strength requirements of the deflector will further constrain the hydrodynamic efficiency of it.*

## *14.4. Conclusions.*

1. *There is no measurable difference in the propulsor efficacy at 100% RPS in the bollard and ahead condition with and without the deflector.*

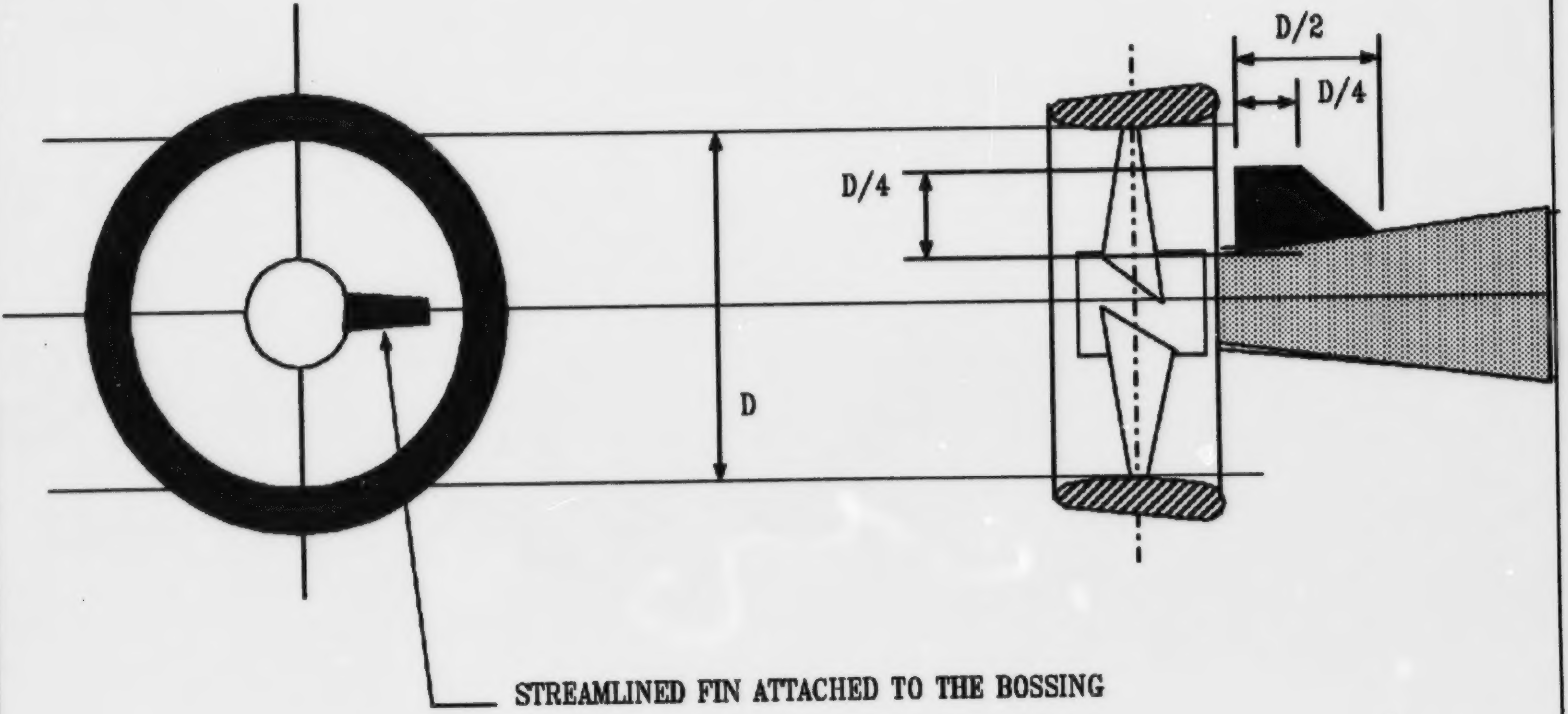
2. *At lower powers developed, the deflector leads to the lowering of the propulsor efficacy in the ahead and astern condition.*



FAIRING BETWEEN NOZZLE AND BLISTER TO BE MADE WITH PUTTY

ONE BLISTER NEEDED

| | | | |
|---|---|---|---|
| **FIGURE TITLE:** CONCEPTUAL DESIGN OF THE NOZZLE BLISTER | | | |
| **PROJECT NAME:** BLOCKAGE OF NOZZLES | | | **PROJECT NR:** |
| **DRAWN BY:** VL | **CHK'D BY:** VL | **SCALE:** NONE | **FIGURE NR:** 14.1 |



| | | | |
|---|---|---|---|
| FIGURE TITLE: BLOCKAGE PREVENTION FIN | | | |
| PROJECT NAME: BLOCKAGE OF SHROUDED PROPS | | | PROJECT NR: |
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: 14.2 |

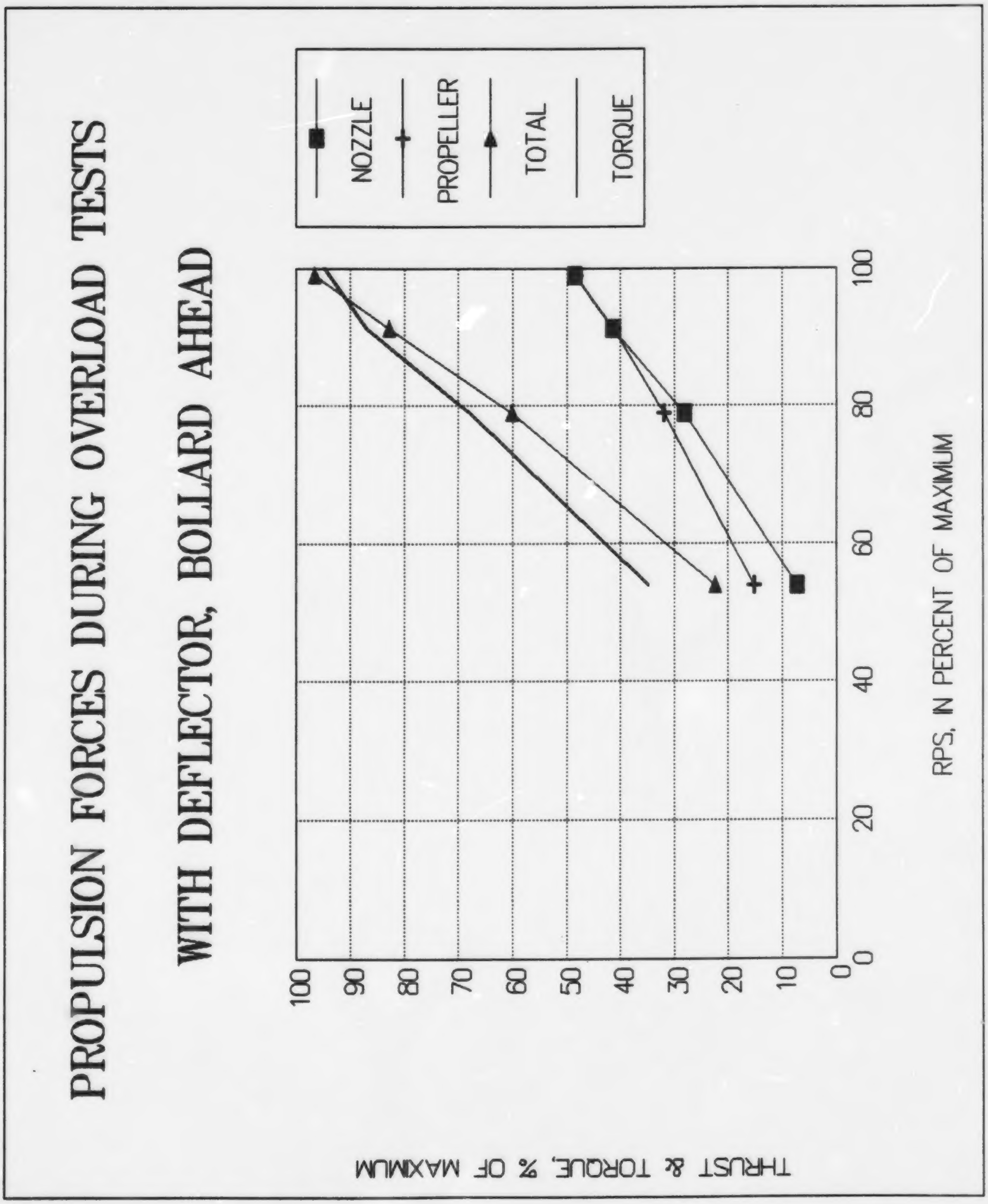
**ARAD**

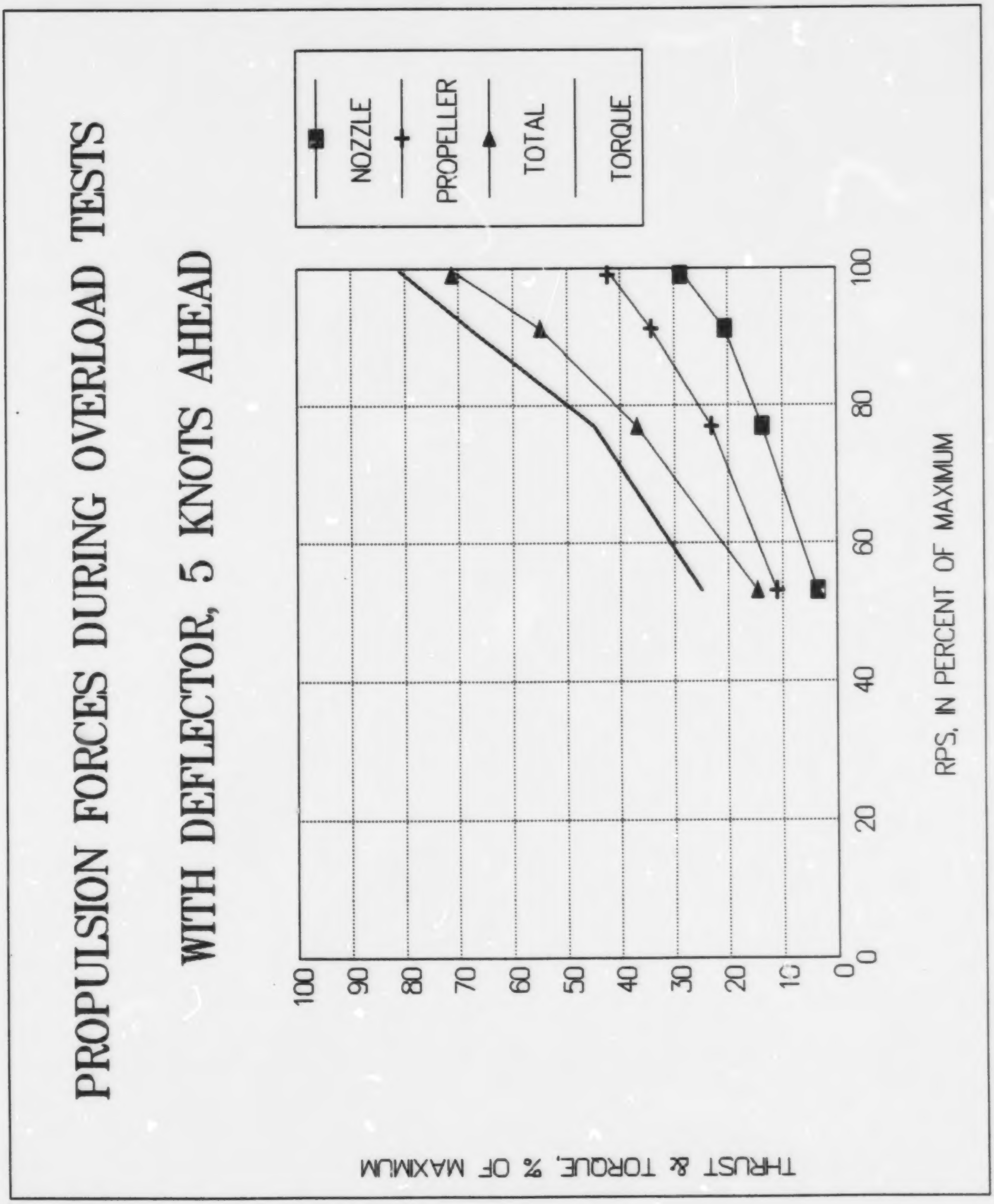
TABLE 14.1

SUMMARY OF OVERLOAD TESTS WITH DEFLECTOR

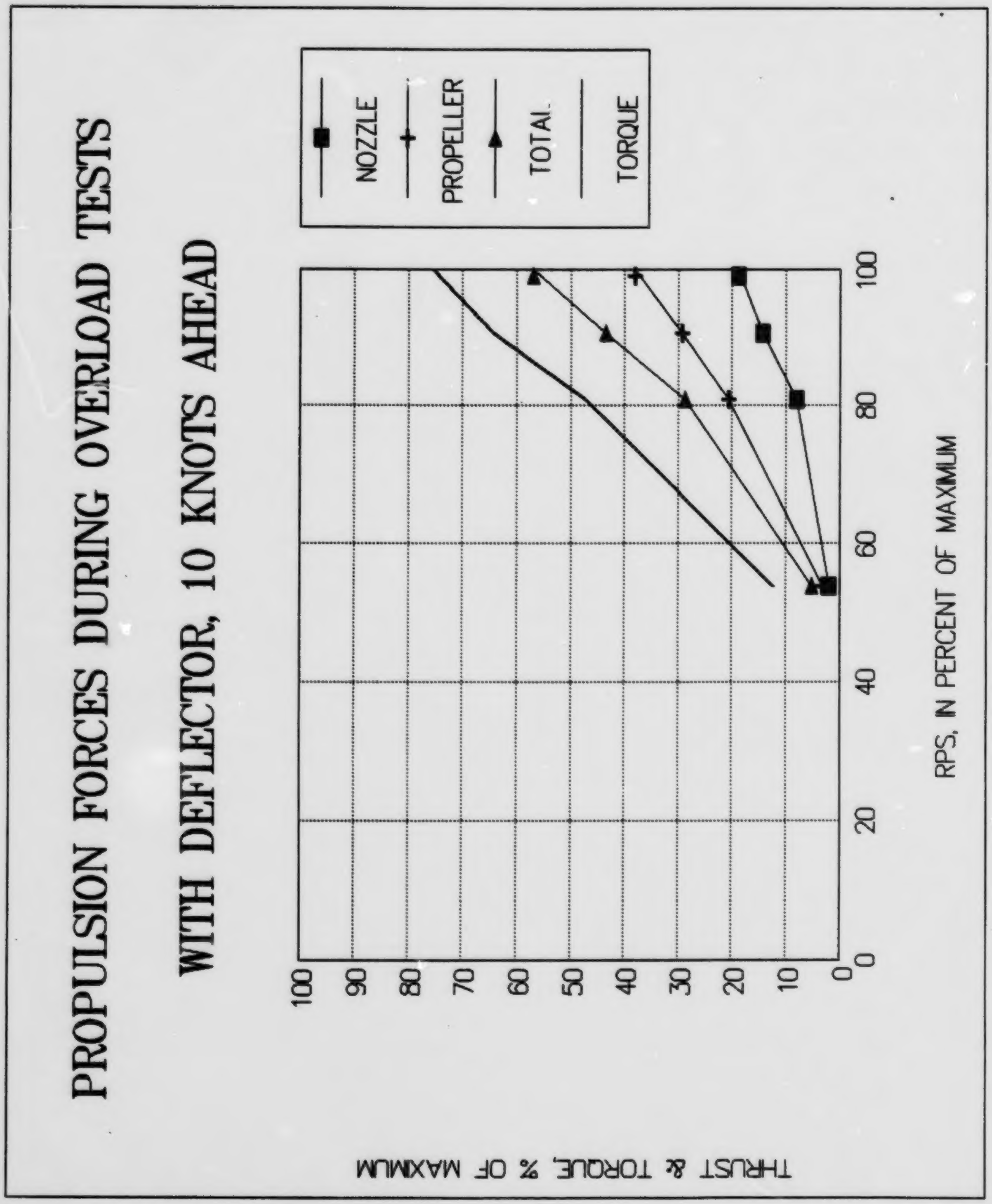
| TEST NUMBER | MODEL SPEED M/S | CENTERLINE RPS IN % OF 8 | SHAFT THRUST % OF 232.5 | NOZZLE THRUST | TOTAL THRUST % OF 232. | TORQUE IN % OF 7.84 |
|---|---|---|---|---|---|---|
| 4 | 0.00 | 100.05 | 48.24 | 48.41 | 96.65 | 94.85 |
| 6 | 0.00 | 91.16 | 41.28 | 41.52 | 82.80 | 87.03 |
| 7 | 0.00 | 78.90 | 31.90 | 28.18 | 60.09 | 67.82 |
| 8 | 0.00 | 53.96 | 15.17 | 7.27 | 22.44 | 34.77 |
| 10 | 0.66 | 53.13 | 11.12 | 3.64 | 14.76 | 24.94 |
| 10 | 0.66 | 76.99 | 23.11 | 13.81 | 36.92 | 44.96 |
| 10 | 0.66 | 91.22 | 34.32 | 20.69 | 55.01 | 67.82 |
| 10 | 0.66 | 99.61 | 42.36 | 28.86 | 71.23 | 81.02 |
| 13 | 1.33 | 53.83 | 3.12 | 1.99 | 5.11 | 12.33 |
| 13 | 1.33 | 80.88 | 20.62 | 8.03 | 28.65 | 47.14 |
| 13 | 1.33 | 90.69 | 29.19 | 14.35 | 43.53 | 64.26 |
| 14 | 1.33 | 99.95 | 38.12 | 18.76 | 56.88 | 75.42 |
| 21 | 1.33 | 97.81 | 31.52 | 30.32 | 61.83 | 56.10 |
| 22 | 1.99 | 91.22 | 25.81 | 11.39 | 37.20 | 44.53 |
| 23 | 1.33 | 78.91 | 15.24 | 6.10 | 21.34 | 23.44 |
| 24 | 1.33 | 53.96 | (1.25) | 3.63 | 2.38 | (7.83) |
| 34 | 0.00 | 100.44 | 49.40 | 55.83 | 105.23 | 100.91 |
| 35 | 0.00 | 100.89 | 50.52 | 51.31 | 101.83 | 103.16 |
| 36 | 0.00 | (100.70) | (56.63) | (44.60) | (101.23) | (119.77) |
| 38 | 1.99 | 100.60 | 23.82 | 3.27 | 27.09 | 49.87 |
| 39 | 1.99 | 92.26 | 15.20 | 0.60 | 15.80 | 29.13 |
| 40 | 1.99 | 89.22 | 11.81 | (2.32) | 9.49 | 27.23 |
| 41 | 1.99 | 53.15 | (14.79) | (10.17) | (24.96) | (23.47) |
| 43 | (0.27) | (106.01) | (58.60) | (39.91) | (98.52) | (121.75) |
| 44 | (0.27) | (96.81) | (48.63) | (32.82) | (81.45) | (103.29) |
| 45 | (0.27) | (83.54) | (35.77) | (21.85) | (57.62) | (77.07) |
| 46 | (0.27) | (58.65) | (17.24) | (8.11) | (25.35) | (41.88) |
| 47 | (0.53) | (104.85) | (54.48) | (31.53) | (86.00) | (116.38) |
| 48 | (0.53) | (96.50) | (46.09) | (26.15) | (72.24) | (99.78) |
| 49 | (0.53) | (83.38) | (33.67) | (16.90) | (50.58) | (76.25) |
| 50 | (0.53) | (57.63) | (14.95) | (6.15) | (21.10) | (39.30) |
| 52 | (0.80) | (105.50) | (51.90) | (27.42) | (79.32) | (112.88) |
| 53 | (0.80) | (96.75) | (42.67) | (21.83) | (64.50) | (94.41) |
| 54 | (0.80) | (83.60) | (30.38) | (13.12) | (43.49) | (71.70) |
| 55 | (0.80) | (58.58) | (12.26) | (3.85) | (16.11) | (35.10) |
| 59 | 0.00 | (105.44) | (62.69) | (45.70) | (108.39) | (127.55) |
| 60 | 0.00 | (105.25) | (62.34) | (43.76) | (106.11) | (128.06) |
| 62 | 0.00 | (96.83) | (53.57) | (38.49) | (92.07) | (111.26) |
| 63 | 0.00 | (83.01) | (40.01) | (30.75) | (70.76) | (86.63) |
| 64 | 0.00 | (59.10) | (21.39) | (14.62) | (36.02) | (51.63) |
| MINIMUM | (0.80) | (106.01) | (62.69) | (45.70) | (108.39) | (128.06) |
| MAXIMUM | 1.99 | 100.89 | 50.52 | 55.83 | 105.23 | 103.16 |
| AVERAGE | 0.39 | 6.17 | (4.94) | (2.05) | (6.99) | (12.73) |

Figure 14.3


PROPULSION FORCES DURING OVERLOAD TESTS
WITH DEFLECTOR, BOLLARD AHEAD
NOZZLE
PROPELLER
TOTAL
TORQUE
THRUST & TORQUE, % OF MAXIMUM
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
RPS, IN PERCENT OF MAXIMUM

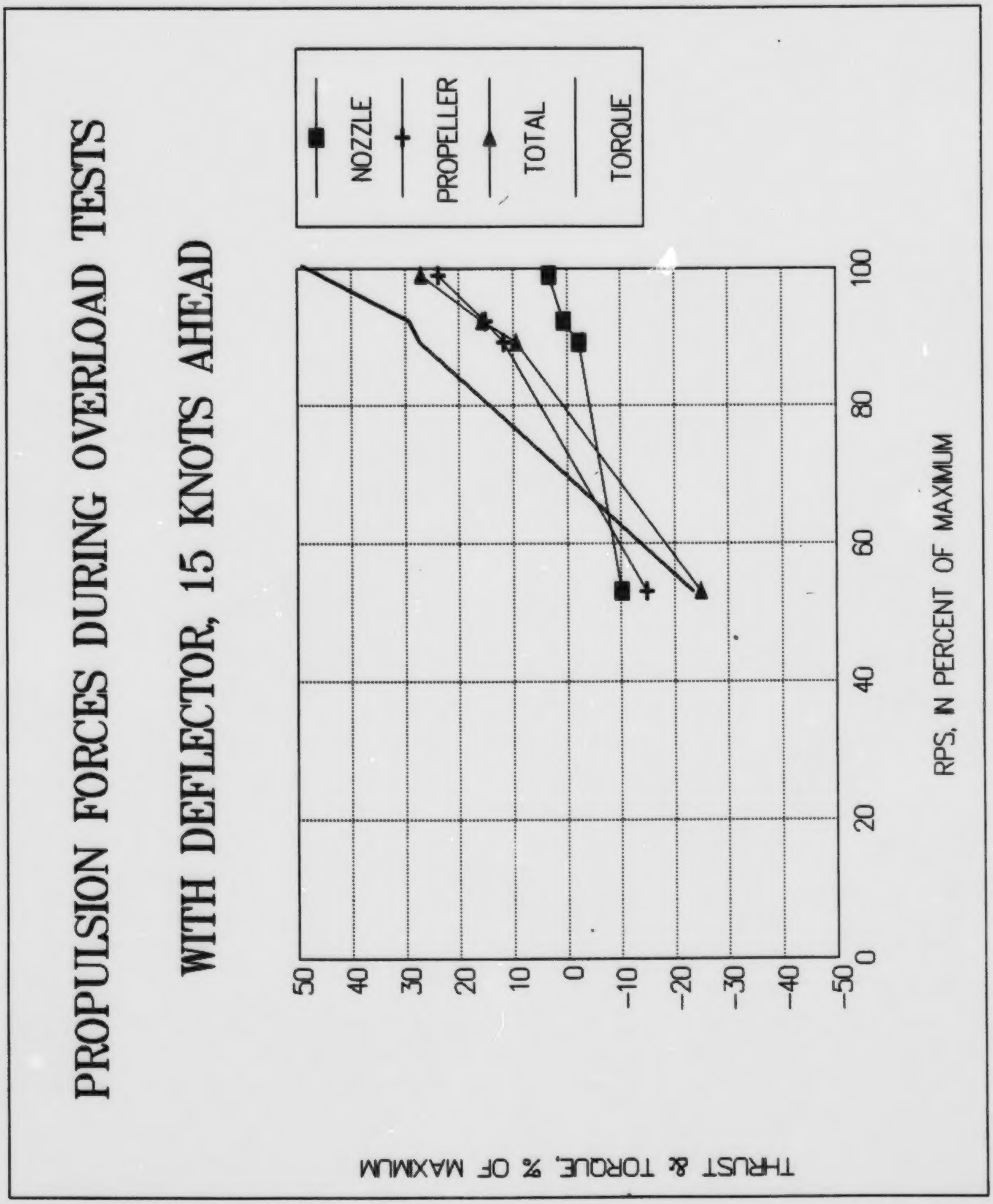


PROPULSION FORCES DURING OVERLOAD TESTS WITH DEFLECTOR, 5 KNOTS AHEAD



PROPULSION FORCES DURING OVERLOAD TESTS
WITH DEFLECTOR, 10 KNOTS AHEAD

Figure 14.6



PROPULSION FORCES DURING OVERLOAD TESTS WITH DEFLECTOR, 15 KNOTS AHEAD

Figure 14.7

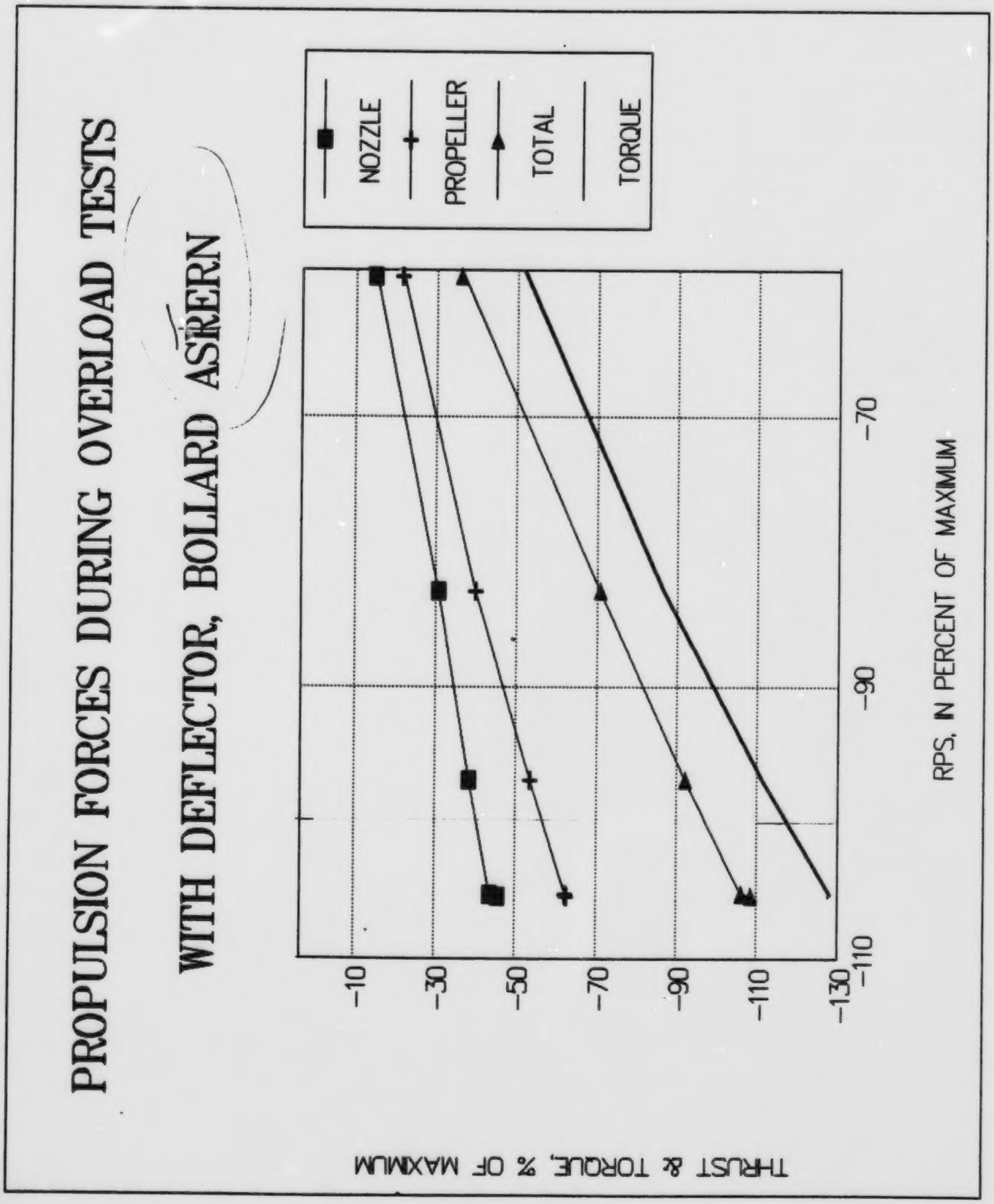

PROPULSION FORCES DURING OVERLOAD TESTS WITH DEFLECTOR, BOLLARD ASTERN

Figure 14.8

PROPULSION FORCES DURING OVERLOAD TESTS

WITH DEFLECTOR, 2 KNOTS ASTERN

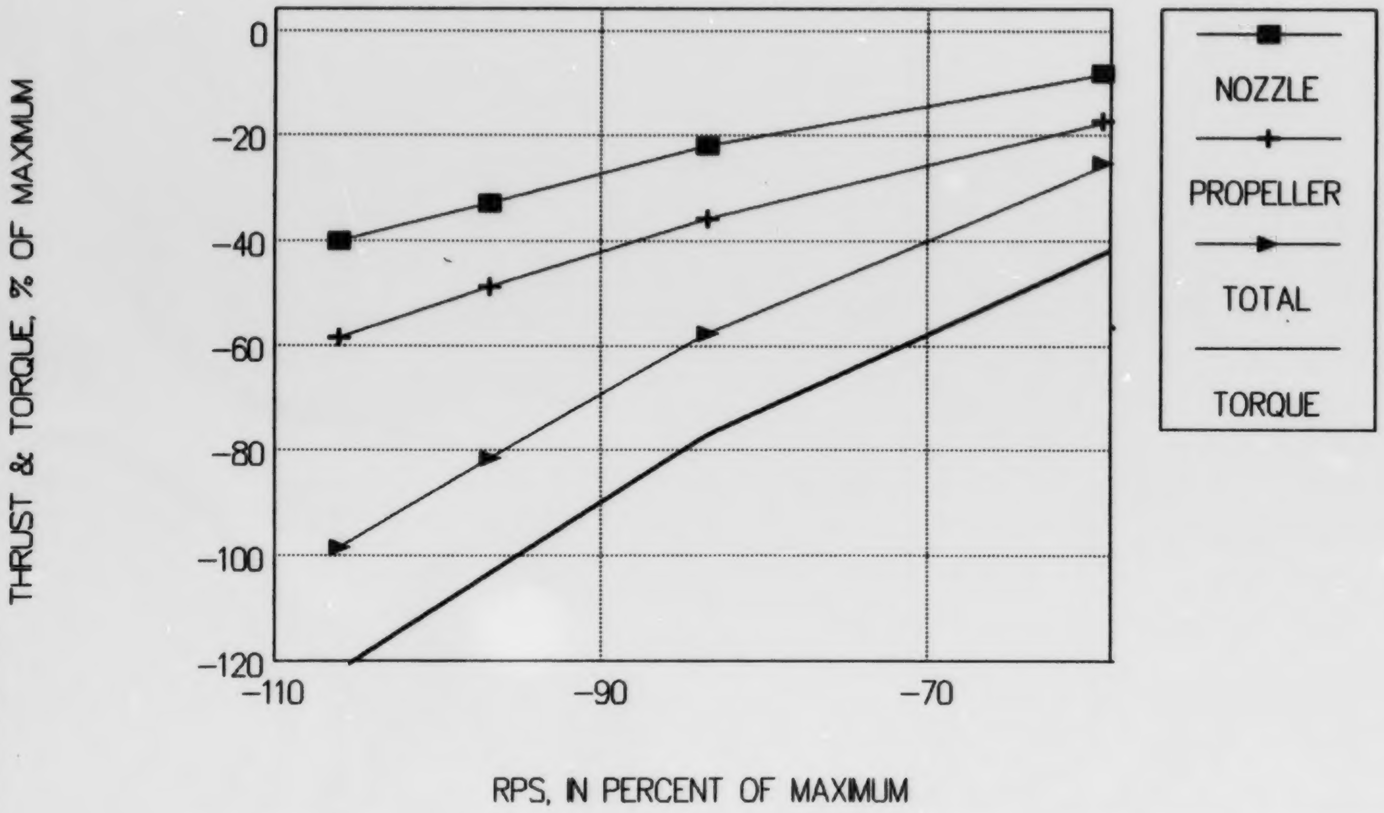
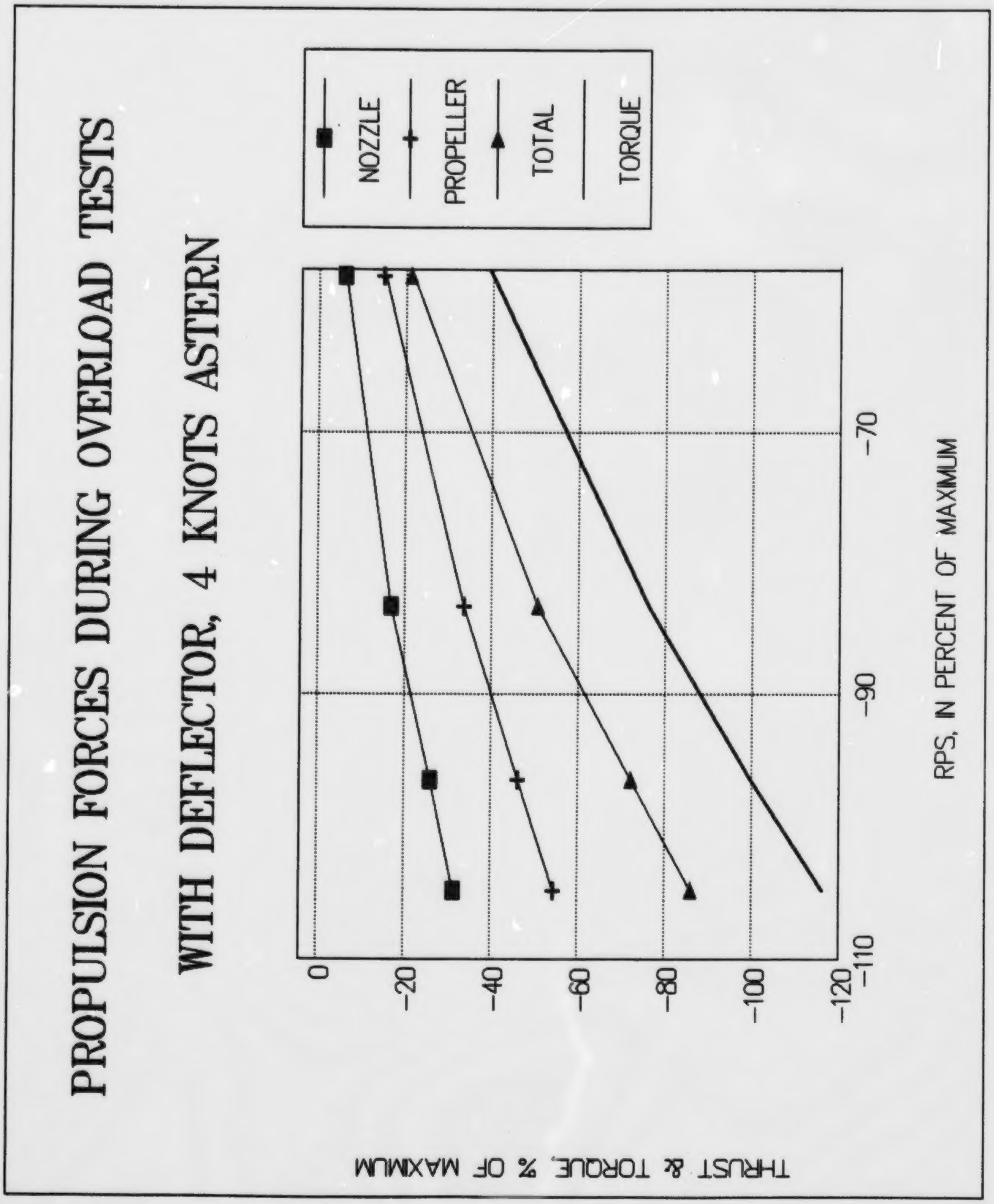


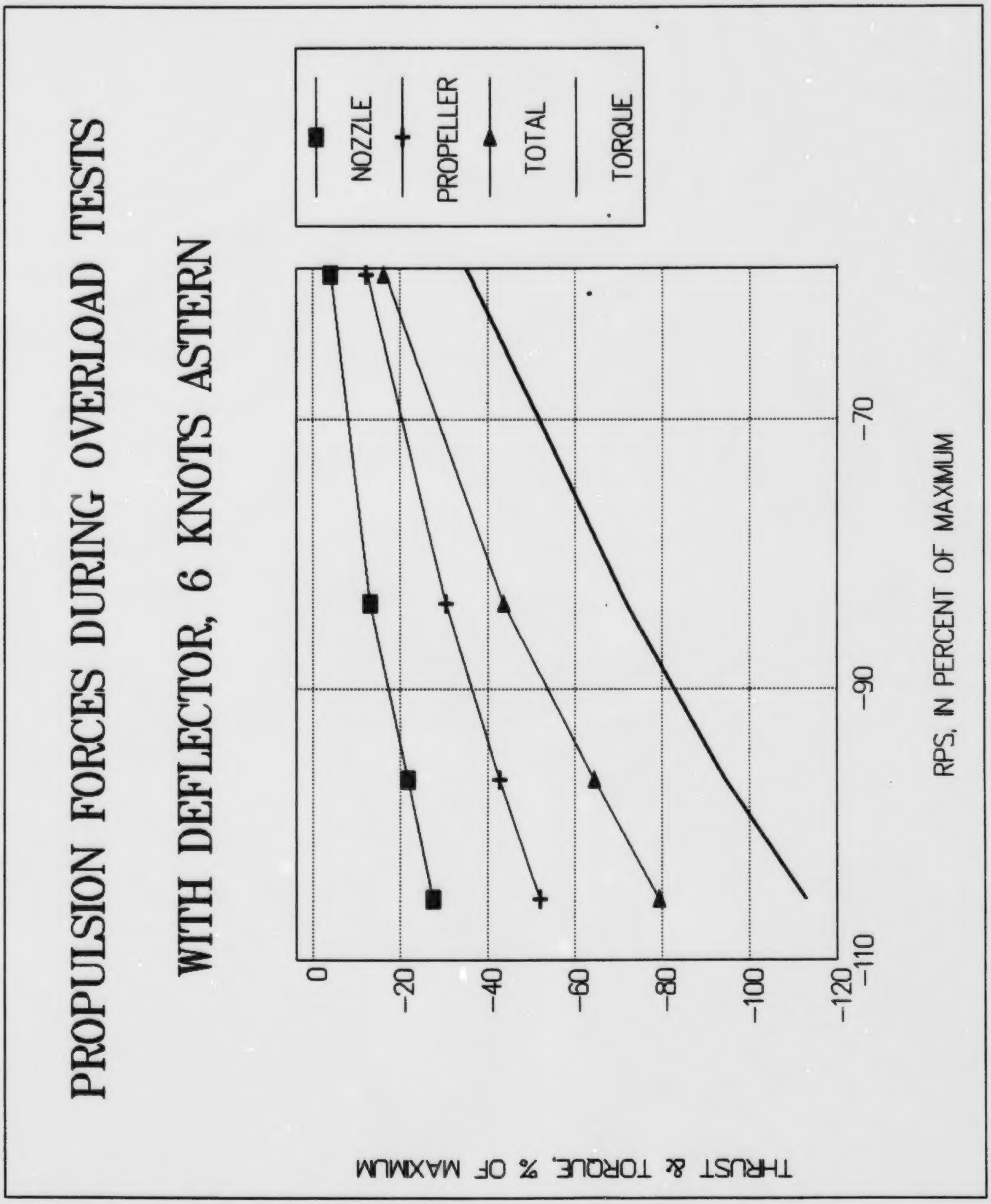
Figure 14.9



PROPULSION FORCES DURING OVERLOAD TESTS

WITH DEFLECTOR, 4 KNOTS ASTERN

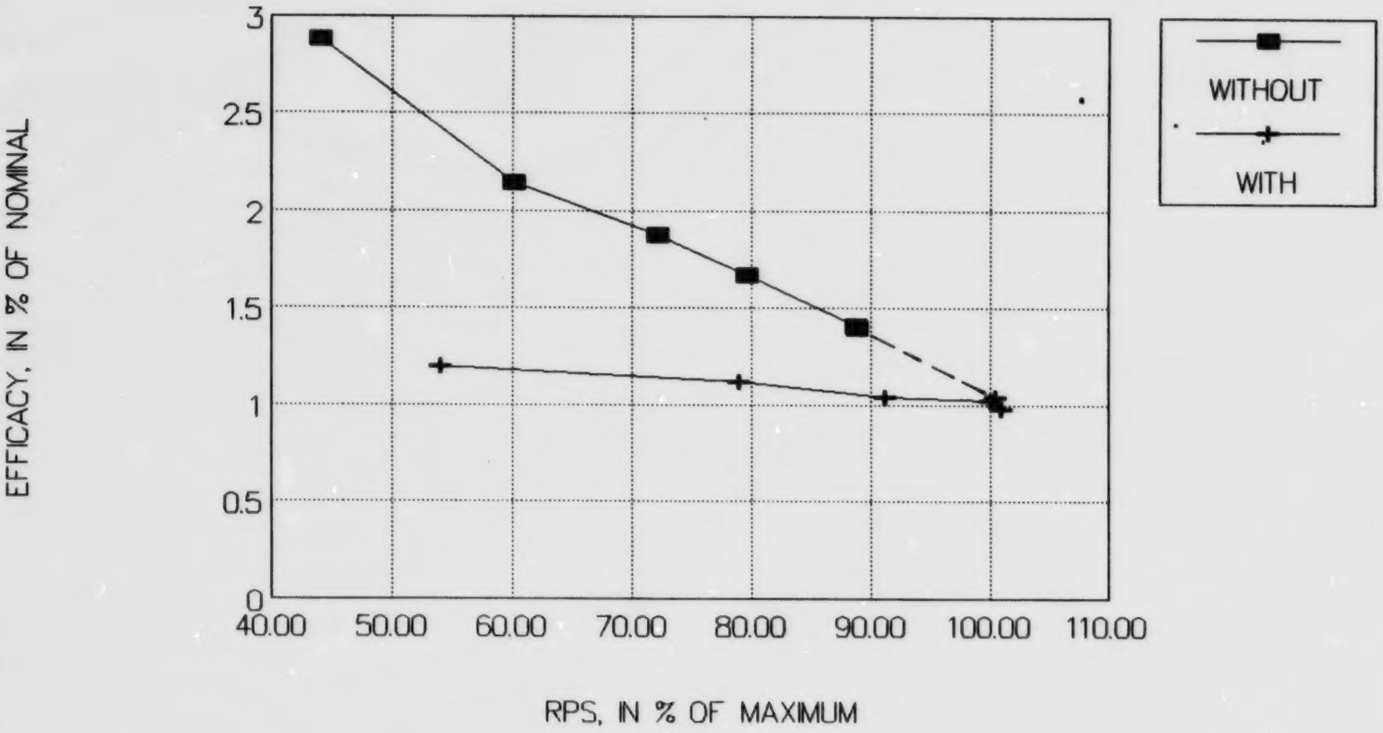
Figure 14.10

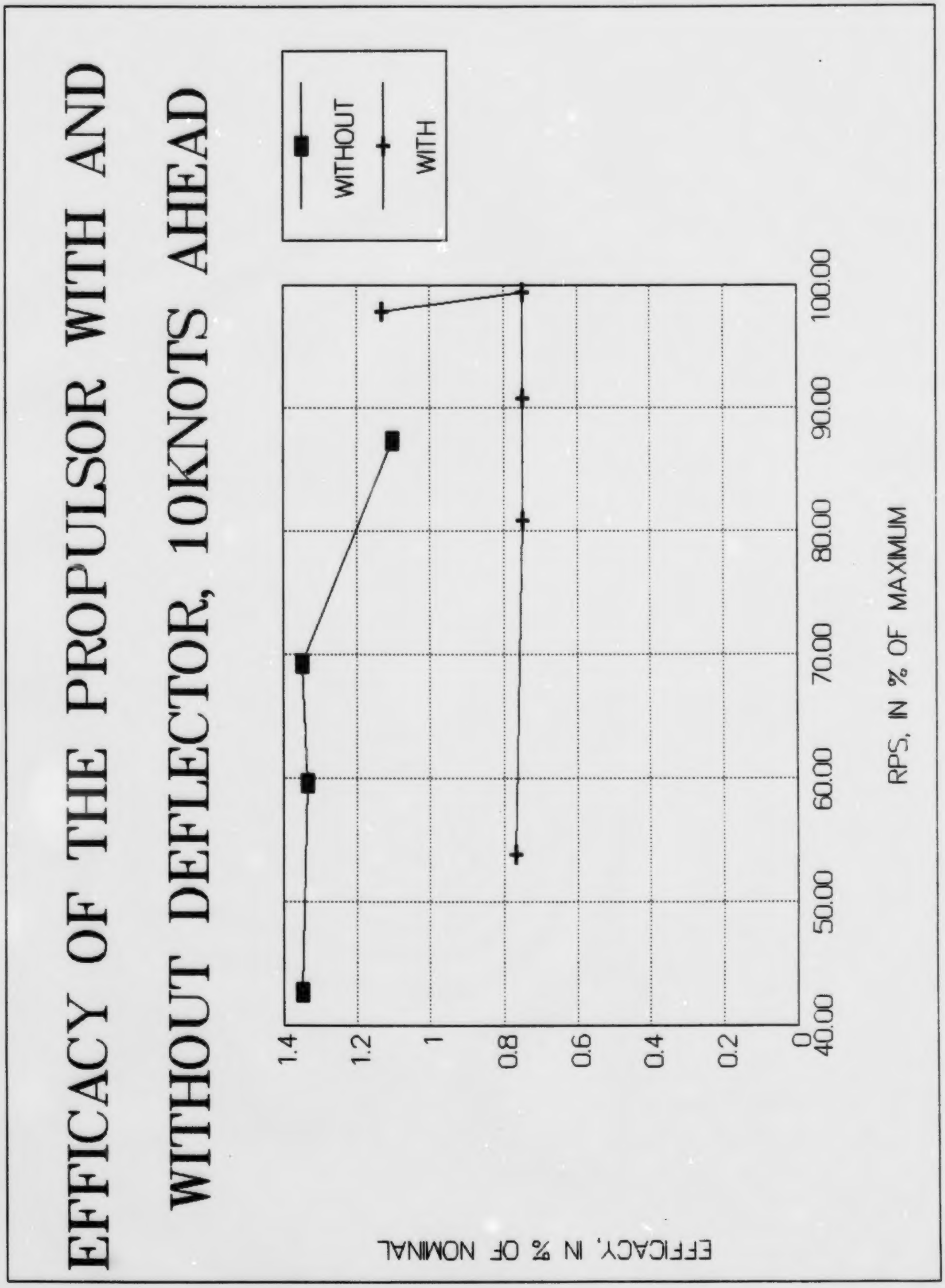


PROPULSION FORCES DURING OVERLOAD TESTS WITH DEFLECTOR, 6 KNOTS ASTERN

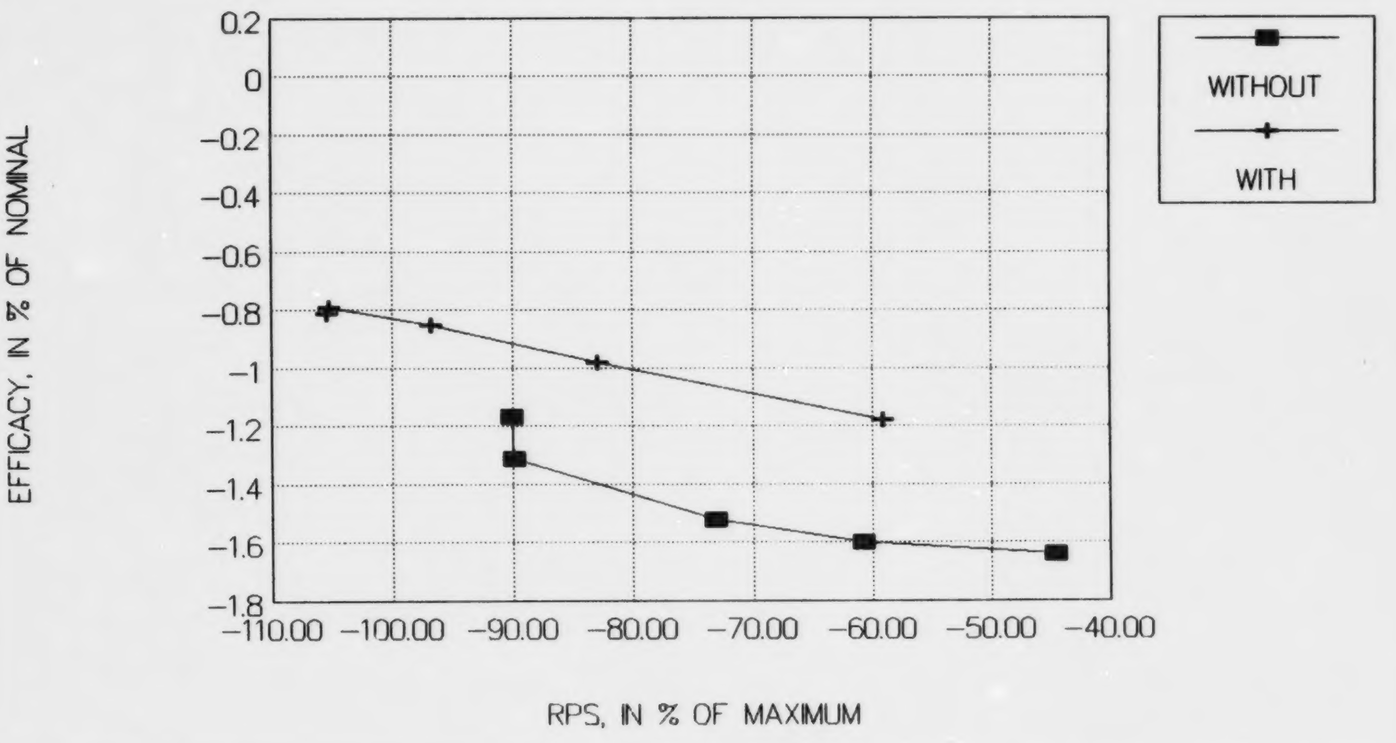
Figure 14.11

# EFFICACY OF THE PROPULSOR WITH AND WITHOUT DEFLECTOR, BOLLARD CONDITION



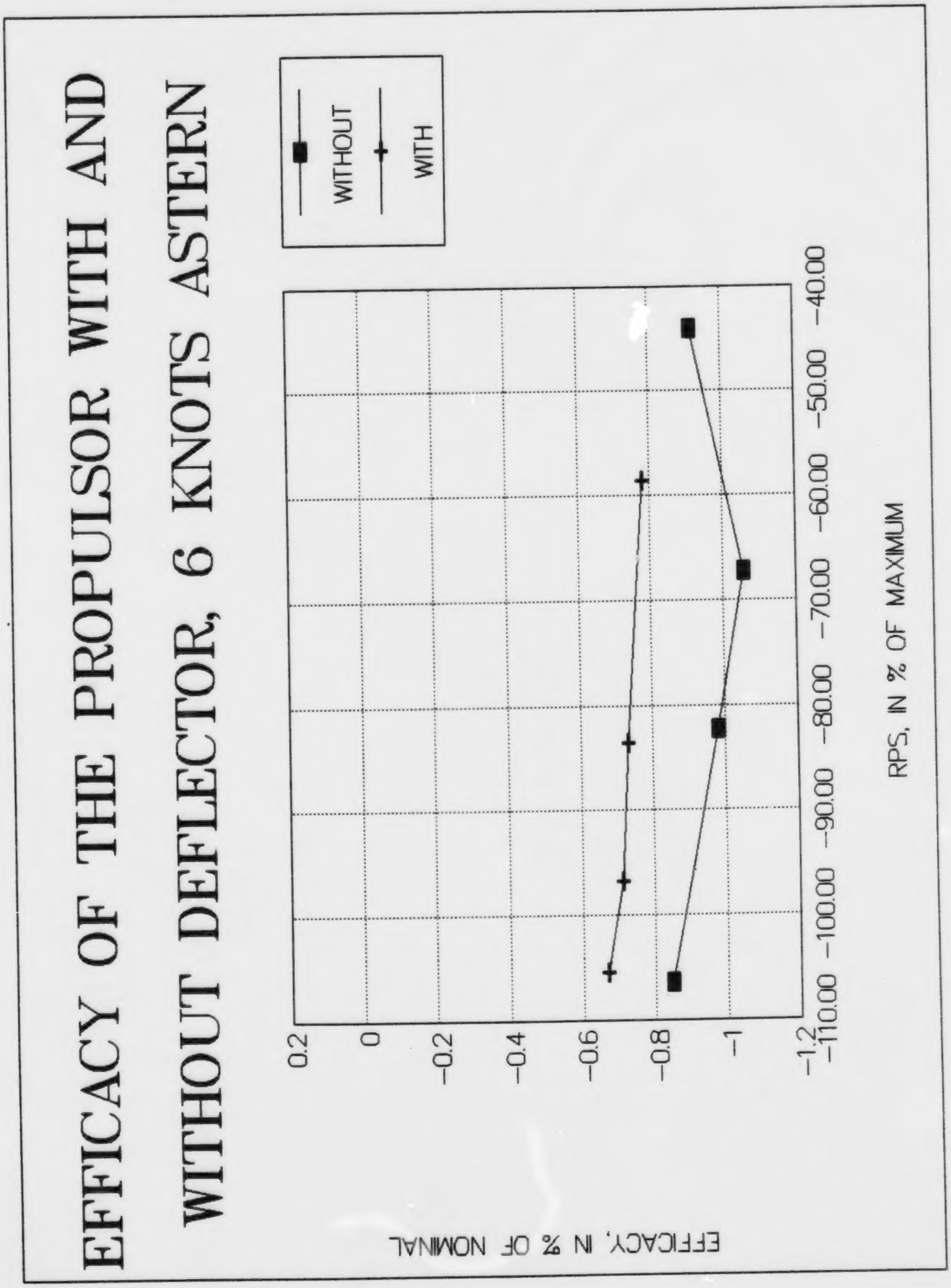


EFFICACY OF THE PROPULSOR WITH AND WITHOUT DEFLECTOR, 10KNOTS AHEAD



EFFICACY OF THE PROPULSOR WITH AND WITHOUT DEFLECTOR, BOLLARD ASTERN

Figure 14.14



EFFICACY OF THE PROPULSOR WITH AND WITHOUT DEFLECTOR, 6 KNOTS ASTERN

## 15. TESTS IN ICE - 235 TEST SERIES RESULTS.

### 15.1 Tests setup

Test series 195 has shown that there was no significant incidence of blockages at a deep draft and with the ice blocks of the sizes specified in the Paragraph 13.2.
Therefore we decided **TO FORCE blockage occurrences** by:

> reducing the draft of the ship to 80%, and
> reducing the size of ice blocks

Furthermore, a deflector was installed on the port side of the centerline skeg. The deflector was attached to the wooden bossing which, later on, was proven to be an insufficiently strong.

### 15.2 Ice coverages

For the runs 1 to 11 the ice coverage was identical with the previous tests (0.76 on the average). Tests 12 and later were done in 1.05 coverage, with significant rafting. A number of ice blocks were also cut in half, thus enabling the blocks to enter the nozzle mouth.

### 15.3 Test results

Table 15.1 summarizes the tests performed in this series. During the run #3 (1 knot astern) the deflector was knocked off the bossing by a block. During the run #6, a half-sized ice piece entered the nozzle and bent the propeller blades. Further tests were done without the centerline shaft working, and have only a comparative value. A detailed description of the run #6 results is given below:

#### 15.3.1. Run #6

The speed was set at 1.5 knots astern. Draft was 80% of the design value. Ice coverage was approximately 80%. All propellers were set to the max RPS. Very heavy ice interaction was noted on all three shafts immediately after the start. Starboard shaft exhibited the highest and most severe degree of interaction. Figures 15.1a, 15.1b, and 15.1c show the traces of the instrumentation during the run.
The centerline nozzle was blocked immediately after the start. After the initial blockage, the rps was reversed and set to zero. Further on, a number of interactions still took place, including the reversals. Thirty five seconds into the run the centerline shaft was stopped due to the propeller damage.

*The maximum values recorded during this run are as follows:*

*TABLE 15.2*

*MAXIMUM VALUES RECORDED DURING THE RUN # 6, SERIES 235*

| | value | | % of nominal |
|---|---|---|---|
| *maximum torque* | *98* | *NM* | *1,250 (7.84 Nm nom)* |
| *maximum thrust* | *980* | *N* | *421 (232.5 N nom)* |
| *maximum nozzle force* | *1284* | *N* | *552 (232.5 N nom)* |

*It is noted that this level of force is due to the non-scaled strength of wax. See APPENDIX L on the properties of wax.*

### *15.4 Analysis of test results*

*Figure 15.2 shows the dependence of the extreme values of the centerline shaft torque and thrust on model speed for the first 6 runs where the centerline power was available.*
*The following observations are made:*

1. *Extreme values of thrust decrease rapidly with the increase of model speed.*
2. *Extreme values of shaft torque are not dependent on model speed.*
3. *The maximum value of the extreme thrust is 4.2 times the value of the total (propeller and nozzle) thrust at the bollard.*
4. *All of the extreme values of thrust are positive (push ahead).*

*Figure 15.3 shows the dependence of the extreme nozzle impact forces on the model speed. The observations are:*

1. *The maximum impact force on the nozzle was 552% of the combined thrust of the system at the bollard (approximately 10 times the nozzle bollard thrust)*
2. *All of the high impact forces were recorded in astern or near bollard condition*
3. *At high speeds the impact forces were low, or none.*
4. *When tested in powered condition (tests 1 to 6) the impact forces were higher than under no power condition (remaining tests).*
5. *Most of the impacts took place when travelling astern or near*

*the bollard condition at low speeds.*

6. *For the tests concluded, the magnitudes of impact forces decrease with the increase of model speed.*

*The influence of ice cover on the magnitude of nozzle impact forces is shown in Figure 15.4. The following is apparent:*

1. *Larger impact forces were recorded at lower coverage.*

2. *There is no significant difference between the amount of impacts in either coverage.*

*Figure 15.5 shows the dependence of the extreme impact values on the model draft. The conclusions are as follows:*

1. *Largest forces were recorded at lower draft.*

2. *There is no detectable trend between the draft and the magnitude of the extreme impact forces.*

*The latter conclusion also applies to the model trim, as expected. The lack of trend is shown on Figure 15.6.*

*When analyzing the impact forces on the nozzle it should be born in mind that the impacts are dynamic phenomena. Hence the inertia distribution of the nozzle and its support plays significant role in the balance of forces and moments. These inertial effects influence not only the readings of the forces, but also their calculated locations. Figure 15.7 shows the computed values of the nozzle impact force location as a function of the impact force magnitude. The following observations are made:*

1. *The extreme impact forces are located at the relative radius* $r/R = 0.25$ *above the nozzle axis.*

2. *The scatter is very high.*

3. *Two of the low magnitude impact forces (together with the inertial effects, added mass etc) are effectively applied outside of the nozzle ring.*

4. *There is a number of impacts applied below the nozzle axis, especially the ones directed astern.*

Table 15.3 shows the number of major interactions with the propellers counted during each run. The following observations are made:

1. On the average, the centerline propeller had the least amount of interactions, during the first 6 tests.
2. The starboard propeller had more interactions than the port one.
3. The amount of major interactions increased drastically when compared with the previous test series (see Table 13.3). This is due to the decreased ice block size and decreased draft.

TABLE 15.4

INFLUENCE OF BLOCK SIZE AND DRAFT ON THE NUMBER OF INTERACTIONS

| Test series | Mean block size | Mean draft | Number of major interactions |
|---|---|---|---|
| series 195 | 0.3m X 0.3m | ~100% | 2.2 per shaft per run |
| series 235 | | 80% | 3.2 per shaft per run |

Figures 15.8 to 15.12 show the results of the correlations between the numbers of the major interactions and the ship/propulsion/ice status. The following observations are made:

1. Port propeller has significantly less interactions than the starboard one (Figure 15.8). The reason for this asymmetry is not understood.
2. The astern RPS (coupled with the astern motion of the ship) generates a number of magnitude more interactions than ahead RPS, as shown in Figure 15.9.
3. The highest RPS (both ahead and astern) are not linked with the highest number of interactions.
4. Increased ice coverage leads to the increased number of interactions on the average (Figure 15.10). However the largest number of interactions was recorded in less than 100% coverage.
5. There is no clear dependence of the number of major interactions on the draft of the vessel, as shown in Figure 15.11. This applies to the specific conditions tested. However the highest number of interactions was registered at reduced draft. The above can be partially explained by the fact that the largest number of interactions occurs when going astern. In this mode, there is so much ice piled up at the stern that most of it goes into the propellers area regardless of the ship's draft.

6. *Model speed, in particular the direction of motion influences strongly the amount of interactions with the wing propellers. Figure 15.12 shows this relationship. When going astern, the number of interactions is an order of magnitude higher than when going ahead.*

7. *The maximum number of interactions when going astern did occurred at a moderate astern speed, not the maximum one.*

8. *In the ahead operations, the number of interactions is not strongly dependent on the speed of the model. The least number of interactions occurred at the speeds between 0.2 to 0.4m/s.*

## *15.5.Blockage of the nozzle when going astern.*

*Test #1 is a good example of the blockage of the nozzle when going astern. Traces of the main signals are given in the Figures 15.13a to 15.13d. The blockage started early in the test, as manifested in the high vibration levels of thrust and torque signals. The blocking piece is visible on the video as positionned vertically, closing the upper half of the port side of the nozzle. The blocking piece edge was resting against the rudder post. At about 75 seconds into the test, the piece went into the propeller, probably pushed in or destabilize by another block. Severe milling took place, leading to the:*

- *lowering of the propeller RPM, leading to the propeller momentary stoppage,*
- *large positive thrust excursion (change from the negative),*
- *general decrease of the astern thrust,*
- *severe longitudinal vibrations of the system,*
- *large negative torque, lasting for approx 5 seconds.*

*The large positive thrust can be explained by the fact that the propeller's leading edge was rounded, not sharp, and therefore the propeller blades were sliding off the block, generating ahead thrust in spite of the astern hydrodynamic thrust.*

## *15.6 Miscellaneous observations of the ice flow under the hull.*

1. *In the astern mode of operations there is a frequent pile up of ice blocks stopped by the skegs of the wing shafts and held there.*

2. *The velocity distribution of the ice blocks interacting with the ship is similar to that of the water surrounding it. Schematic of this distribution is shown in Figure* 13.42

3. *There is an evidence of very thick boundary layer adjacent to*

the hull. It manifests itself by the motion of milled ice particles and the whole blocks with the ship in the bottom bow area.

4. Wing propellers hull wash reaches to the forward area, as evidenced by the motion of the milled particles.

5. When operating astern, the wing propellers kick ice along the skeg inwards and down, thus working against the force of buoyancy.

6. When the wing propellers are stopped, there is no interaction between them and the blocks, as all blocks float above them.

7. When the wing propellers are stopped, they drag ice blocks ahead of them creating the danger of breaking the blades. The ice blocks are piled up by the stopped blades and the skeg of the bossings.

8. There is no ice flowing thru the propellers in the bollard stern condition (with the centerline shaft stopped)

### 15.7 Model propeller damage.

Photos 15.14 and 15.15 show the center shaft propeller damage which occurred during the run #6, test 235. When examining this damage, the following issues should be born in mind:

1. Ice strength was far in excess (15 fold) of the properly scaled sea ice.

2. The center propeller was made of soft bronze material, unlike the wing propellers, made of very hard alloy.

3. The center propeller had blunt leading and trailing edges, not sharpened as the wing propellers had.

4. Centerline propulsion motor had very large torque surplus. No clutches were present in the system.

5. The centerline propeller weighted 1/2 of the wing propeller weight.

The following observations can be made when examining the damage:

1. Three blades are bent out of four. This shows that the propeller stalled in less than 1/2 revolution.

2. Two blades are bent in one direction (clockwise), and one is bent counterclockwise. This shows that the reversing of the RPM did also do damage to the blade.

3. The bent lines lie above the root section (5 to 8 mm).

4. The force which bent the blade is estimated as follows. Section modulae (elastic SMy and plastic SMp) of the blade section:

   SMy = 0.06 * 0.004^2/6 = 1.6 * 10^ -7 m^3
   SMp = 1.5 * SMy = 2.4 * 10^ -7 m^3

   Strength of the material:

   sigma yld = 200 Mpa     sigma ult = 235 MPa

   Bending moment yielding the section:

   BMy = 32 Nm   (elastic yield)
   BMp = 56 Nm   (fully plastic hinge)

These values can be compared against the hydrodynamic torque developed by each blade in a bollard condition:

Q hydro = 8Nm/4 = 2Nm

Thus the bending moment approximately 16 to 28 times higher than the hydrodynamic blade torque destroyed the blades. **Full scale** trials show that such moments are not encountered in the shrouded propellers (References 3, 4, 5, 7 and 8).

## 15.8 Conclusions

*The following conclusions are made from this test series.*

1. *Maximum impact forces on the nozzle are higher when the nozzle propeller operates than when the power is off, at the reduced draft.*
2. *The ratio of the extreme impact forces in powered condition to those in an unpowered condition is 2:1.*
3. *The extreme thrust on the centerline shaft recorded was approximately 10 times the propeller bollard thrust and 1.8 times the maximum nozzle impact force.*
4. *The extreme value of the torque recorded was 12.5 times the bollard hydrodynamic torque, for the conditions tested.*
5. *The maximum values of the centerline propeller torque and thrust diminish with the increase of model speed.*
6. *All of the high impact forces on the nozzle were recorded in the astern or near bollard conditions.*
7. *The maximum impact force on the nozzle was 552% of the nominal combined bollard thrust of the system.*
8. *At high model speeds ahead the impact forces were low, if any.*
9. *The magnitude of impact forces on the nozzle decrease with the increase of model speed.*
10. *The degree of ice coverage is not correlated strongly with the magnitude of impact forces.*
11. *Lower draft leads to higher impact forces. There is no trend between the magnitude of the forces and the draft.*
12. *The extreme nozzle impact forces are effectively located at r/R = 0.25 above the nozzle axis.*
13. *There is a number of impacts located below the nozzle axis, especially when going astern. This is confirmed by the wax marks on the lower part of nozzle mouth.*
14. *Smaller ice blocks enter the nozzle mouth and create the blockage/milling condition.*
15. *When comparing this test results with the previous tests in ice the following general conclusions can be drawn:*

*TABLE 15.5*

*Comparison of the main test results*

| *Test conditions* | *Number of interactions* | *Blockages* |
|---|---|---|
| *deep draft*<br>*large pieces* | *small* | *few* |
| *light draft*<br>*small pieces* | *high* | *many* |

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TABLE 15.1

TEST 235 - SUMMARY OF MEAN VALUES

| TEST NR | SPEED M/S | MODEL DRAFT % OF | TRIM | COVER MAX | CENTERLINE SHAFT THRUST N | CENTERLINE SHAFT TORQUE NM | CENTERLINE SHAFT SPEED RPS | WING PROPELLER RPS PORT | WING PROPELLER RPS STARB'D | TOW FORCE N |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0.067 | 80 | 0 | 8/10 | (230.00) | (15.31) | (7.89) | (6.31) | (7.01) | 67.85 |
| 2 | 0.133 | 80 | 0 | 8/10 | 96.67 | 6.13 | 7.92 | 8.78 | 8.40 | (371.30) |
| 3 | -0.133 | 80 | 0 | 8/10 | (64.25) | (11.47) | (5.94) | (4.51) | (5.95) | 58.93 |
| 5 | 0.398 | 80 | 0 | 8/10 | 128.50 | 7.98 | 7.51 | 9.16 | 9.01 | (321.30) |
| 6 | -0.199 | 80 | 0 | 8/10 | 48.80 | 6.17 | 0.18 | (4.98) | (5.11) | 0.19 |
| 7 | 0.664 | 80 | 0 | 8/10 | (5.62) | (4.68) | 0.03 | 8.88 | 8.38 | (133.70) |
| 9 | -0.067 | 80 | 0 | 8/10 | (7.86) | (4.94) | 0.00 | (7.09) | (7.27) | 70.43 |
| 10 | 0.133 | 80 | 0 | 8/10 | 4.36 | (4.48) | 0.00 | 8.11 | 7.67 | (135.80) |
| 11 | -0.199 | 80 | 0 | 8/10 | 4.86 | (4.41) | 0.00 | (2.35) | (5.73) | (30.47) |
| 12 | 0.199 | 100 | 0 | 10/10 | 3.00 | (5.18) | 0.00 | 0.00 | 0.00 | 114.40 |
| 13 | -0.193 | 100 | 0 | 10/10 | 0.17 | (5.08) | 0.00 | 0.00 | 0.00 | (123.20) |
| 14 | 0.199 | 100 | 0 | 10/10 | (2.37) | (5.06) | 0.00 | 9.03 | 8.46 | (228.20) |
| 15 | -0.199 | 100 | 0 | 10/10 | 4.98 | (4.98) | 0.00 | (8.14) | (6.70) | 12.12 |
| 16 | 0.199 | 100 | 0 | 10/10 | 3.37 | (4.96) | 0.00 | 9.44 | 8.96 | (57.04) |
| 17 | -0.199 | 100 | 0 | 10/10 | 4.14 | (4.92) | 0.00 | 9.30 | 9.17 | (173.40) |
| 18 | 0.664 | 100 | 0 | 10/10 | 1.73 | (4.91) | 0.00 | 9.15 | 8.71 | (148.10) |
| 19 | -0.199 | 100 | 0 | 10/10 | 3.26 | (4.83) | 0.00 | (7.62) | (7.63) | 49.55 |
| 21 | 0.133 | 100 | 0 | 10/10 | (0.35) | (4.84) | 0.00 | 8.98 | 8.53 | (256.50) |
| 22 | -0.133 | 100 | 0 | 10/10 | (2.37) | (4.85) | 0.00 | (5.78) | (9.19) | 68.70 |
| 23 | 0 | 100 | 0 | 10/10 | 0.54 | (4.89) | 0.00 | (8.53) | (8.77) | 151.20 |
| 24 | 0 | 100 | 0 | 10/10 | (1.37) | (4.86) | 0.00 | 8.96 | 8.61 | (334.40) |
| 25 | 0 | 100 | 0 | 10/10 | (4.57) | (4.83) | 0.00 | (8.65) | (8.98) | 162.20 |
| 26 | 0.199 | 100 | AST | 10/10 | 2.17 | (0.47) | 0.00 | 9.14 | 8.89 | (237.90) |
| 27 | -0.199 | 100 | AST | 10/10 | 4.19 | (4.60) | 0.00 | (8.21) | (7.83) | 337.80 |

Figure 15.1a

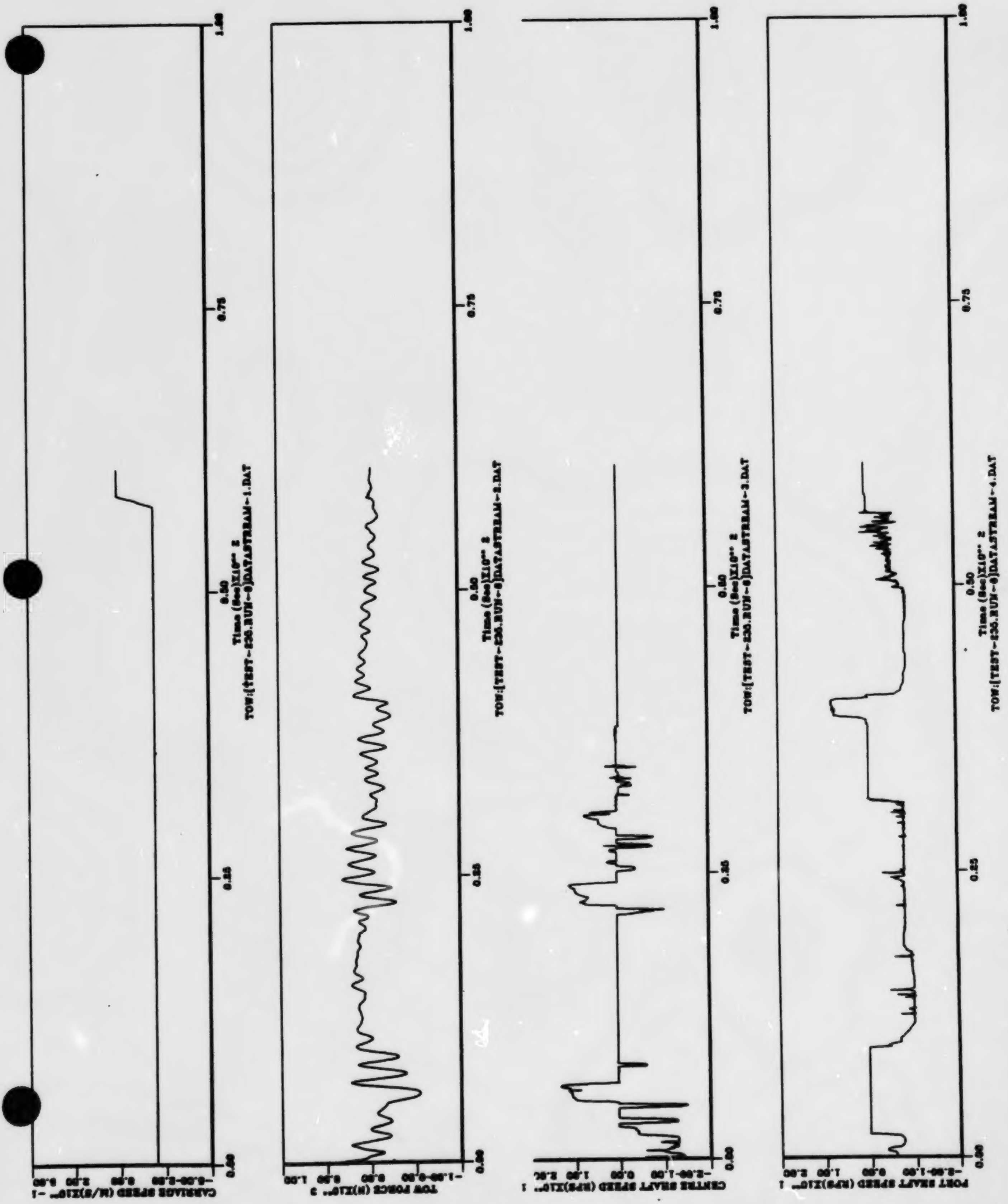

CARRIAGE SPEED (M/S)X10** -1
-5.00 -2.50 0.00 2.50 5.00
Time (Sec)X10** 2
TOW:[TEST-230.RUN-8]DATASTREAM-1.DAT
0.00 0.25 0.50 0.75 1.00
TOW FORCE (N)X10** 3
-1.00 -0.50 0.00 0.50 1.00
Time (Sec)X10** 2
TOW:[TEST-230.RUN-8]DATASTREAM-2.DAT
0.00 0.25 0.50 0.75 1.00
CENTRE SHAFT SPEED (RPS)X10** 1
-2.00 -1.00 0.00 1.00 2.00
Time (Sec)X10** 2
TOW:[TEST-230.RUN-8]DATASTREAM-3.DAT
0.00 0.25 0.50 0.75 1.00
PORT SHAFT SPEED (RPS)X10** 1
-2.00 -1.00 0.00 1.00 2.00
Time (Sec)X10** 2
TOW:[TEST-230.RUN-8]DATASTREAM-4.DAT
0.00 0.25 0.50 0.75 1.00

Figure 15.1b

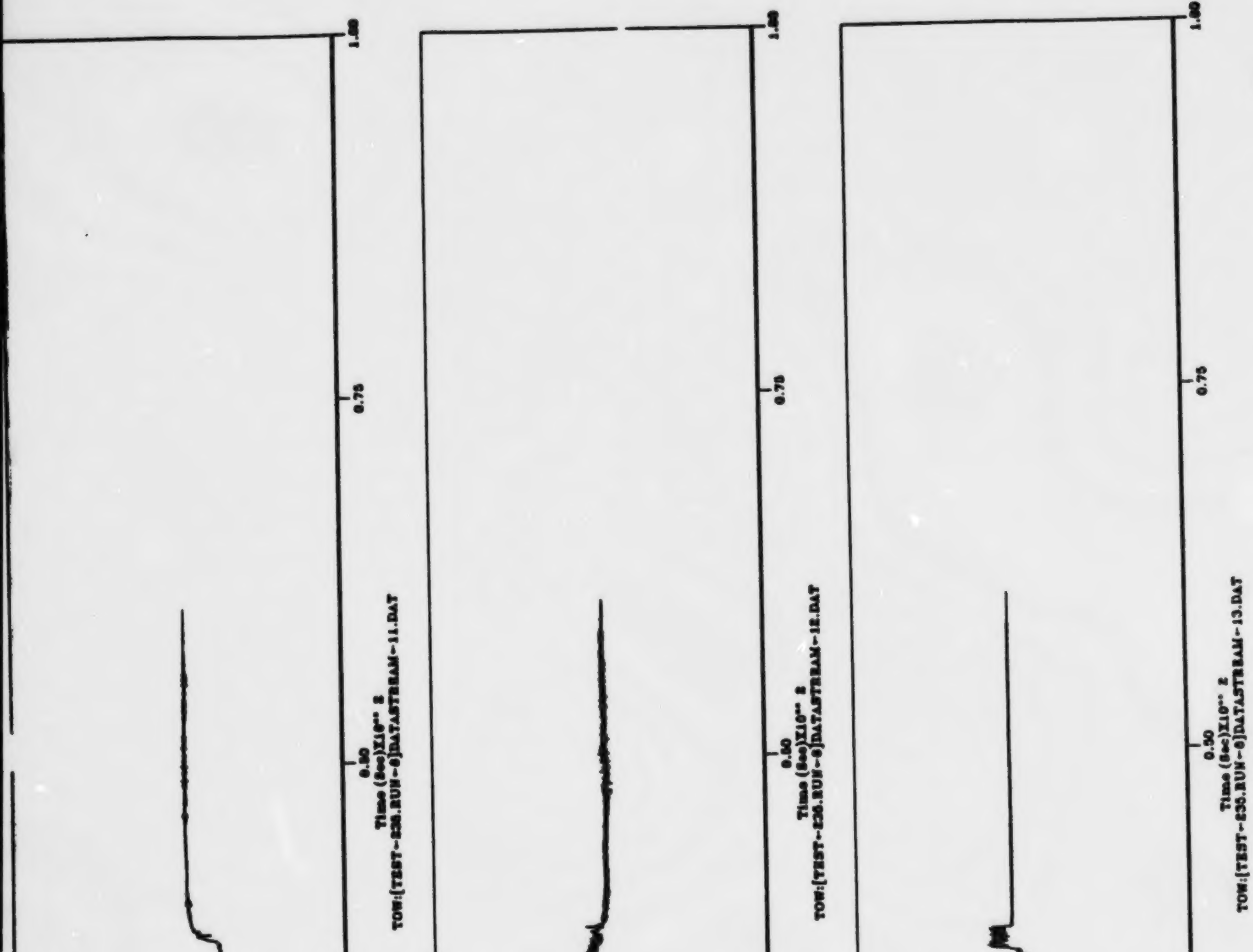

NOZZLE TORSION [φ0 Gt] (Nm)X10** 2
2.00
1.00
0.00
-1.00
-2.00
0.00
0.25
0.50
0.75
1.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-8]DATASTREAM-11.DAT
CENTER THRUST (N)X10** 3
1.00
0.50
0.00
-0.50
-1.00
0.00
0.25
0.50
0.75
1.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-8]DATASTREAM-12.DAT
CENTER TORQUE (Nm)X10** 2
2.00
1.00
0.00
-1.00
-2.00
0.00
0.25
0.50
0.75
1.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-8]DATASTREAM-13.DAT

Figure 15.1c

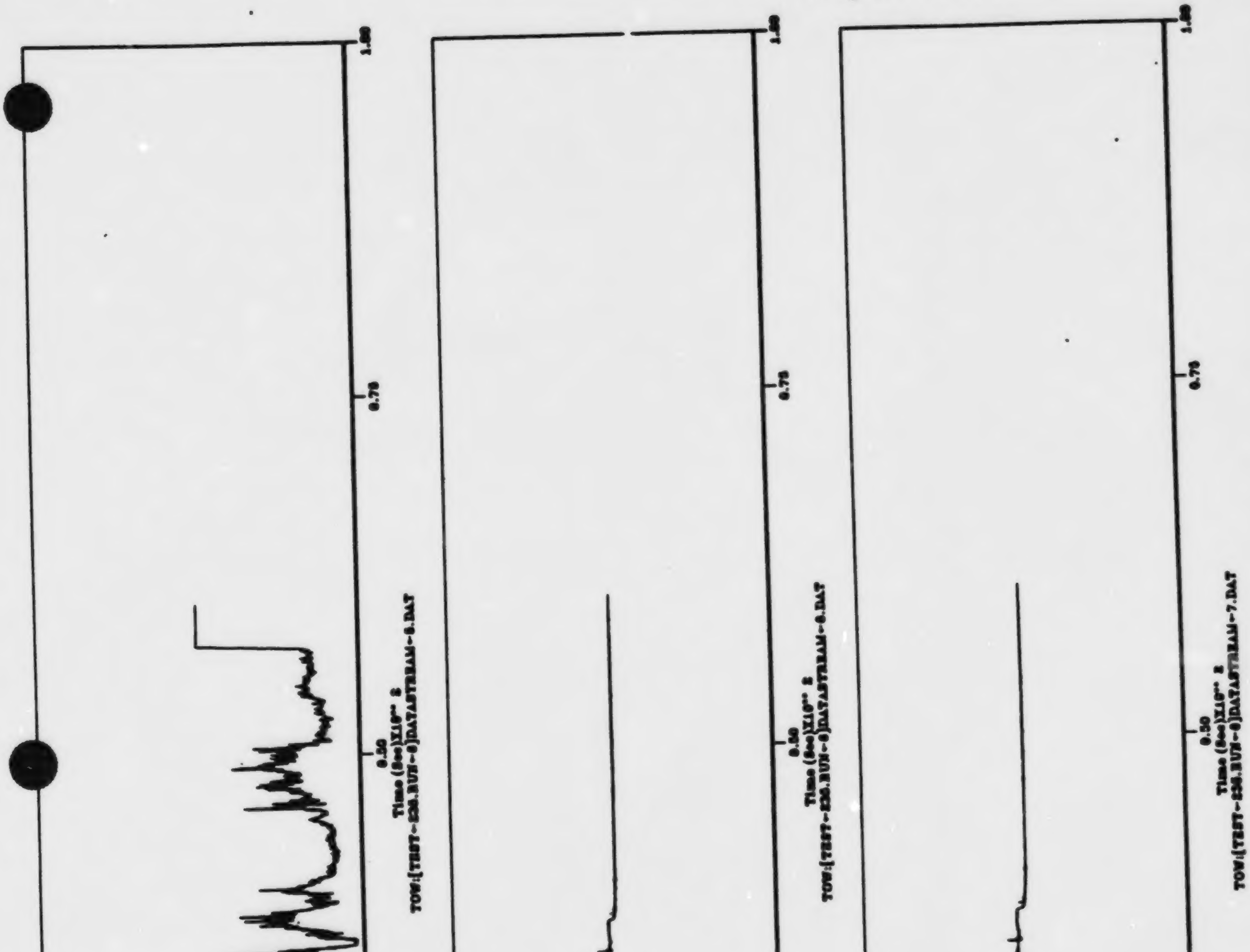
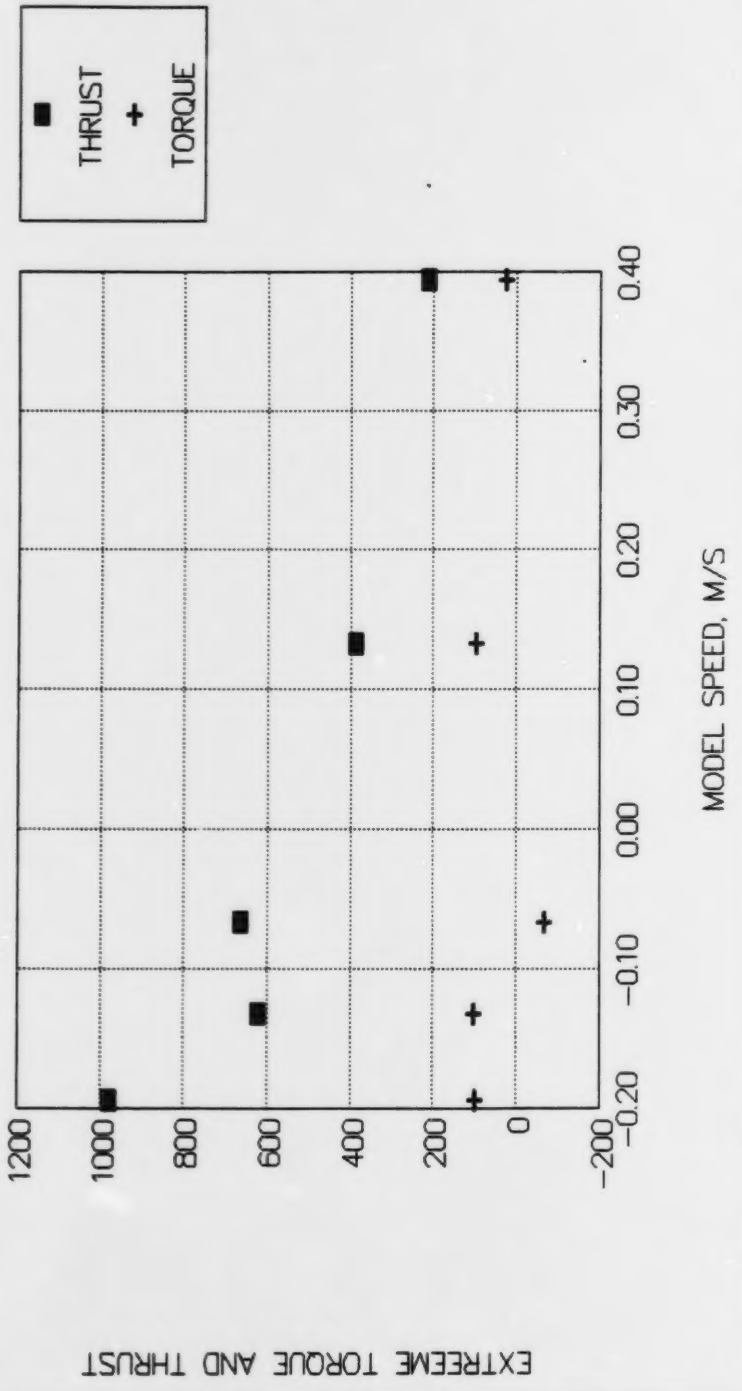
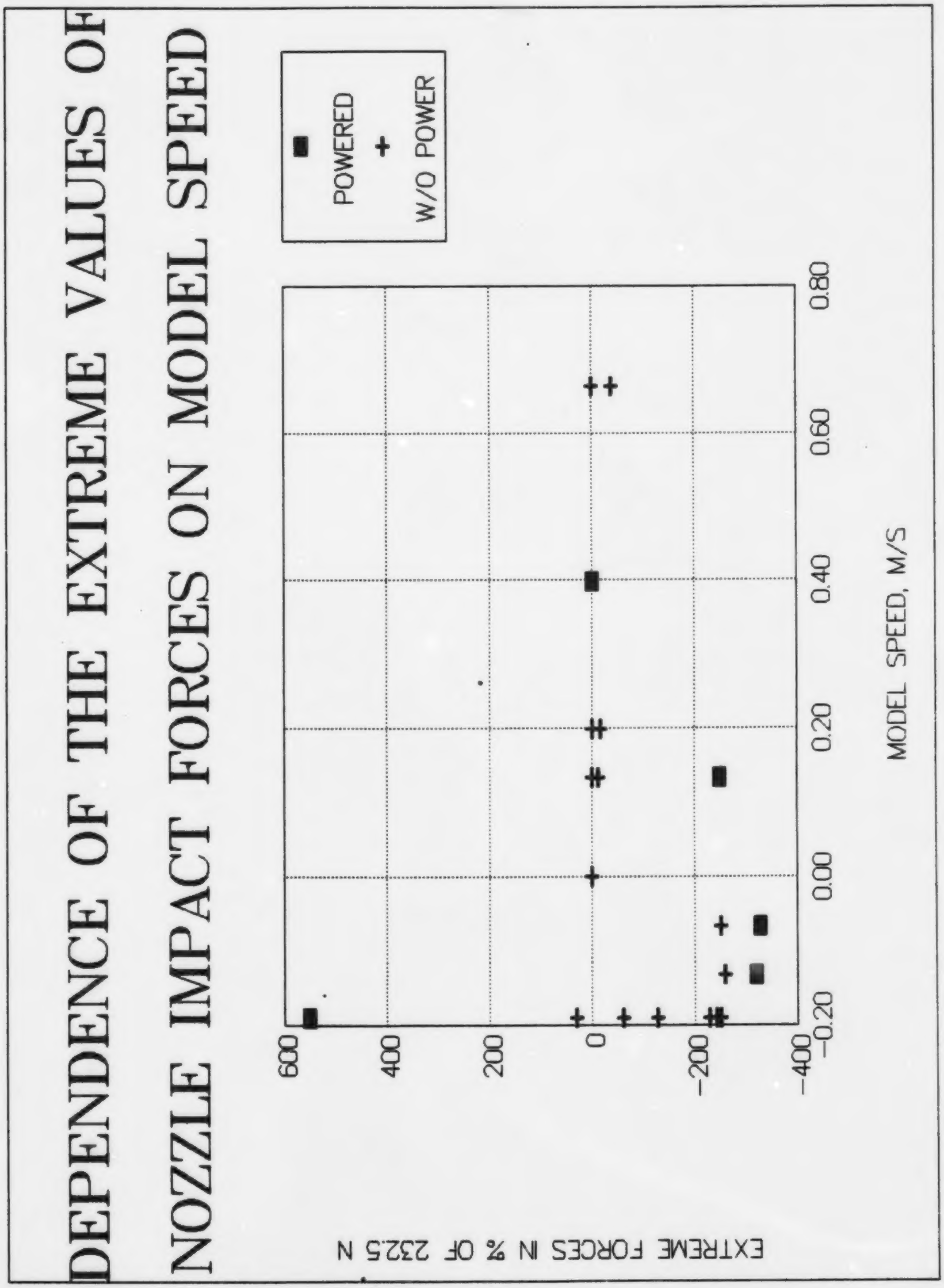

STEERD. SHAFT SPEED (RPS)X10** 1
1.00
0.50
0.00
-0.50
-1.00
0.00
0.25
0.50
0.75
1.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-6]DATASTREAM-5.DAT
NOZZLE FORCE [#1 GAUGE] (Nm)X10** 2
5.00
2.50
0.00
-2.50
-5.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-6]DATASTREAM-6.DAT
NOZZLE FORCE [#2 GAUGE] (Nm)X10** 2
5.00
2.50
0.00
-2.50
-5.00
Time (Sec)X10** 2
TOW:[TEST-236.RUN-6]DATASTREAM-7.DAT

Figure 15.2

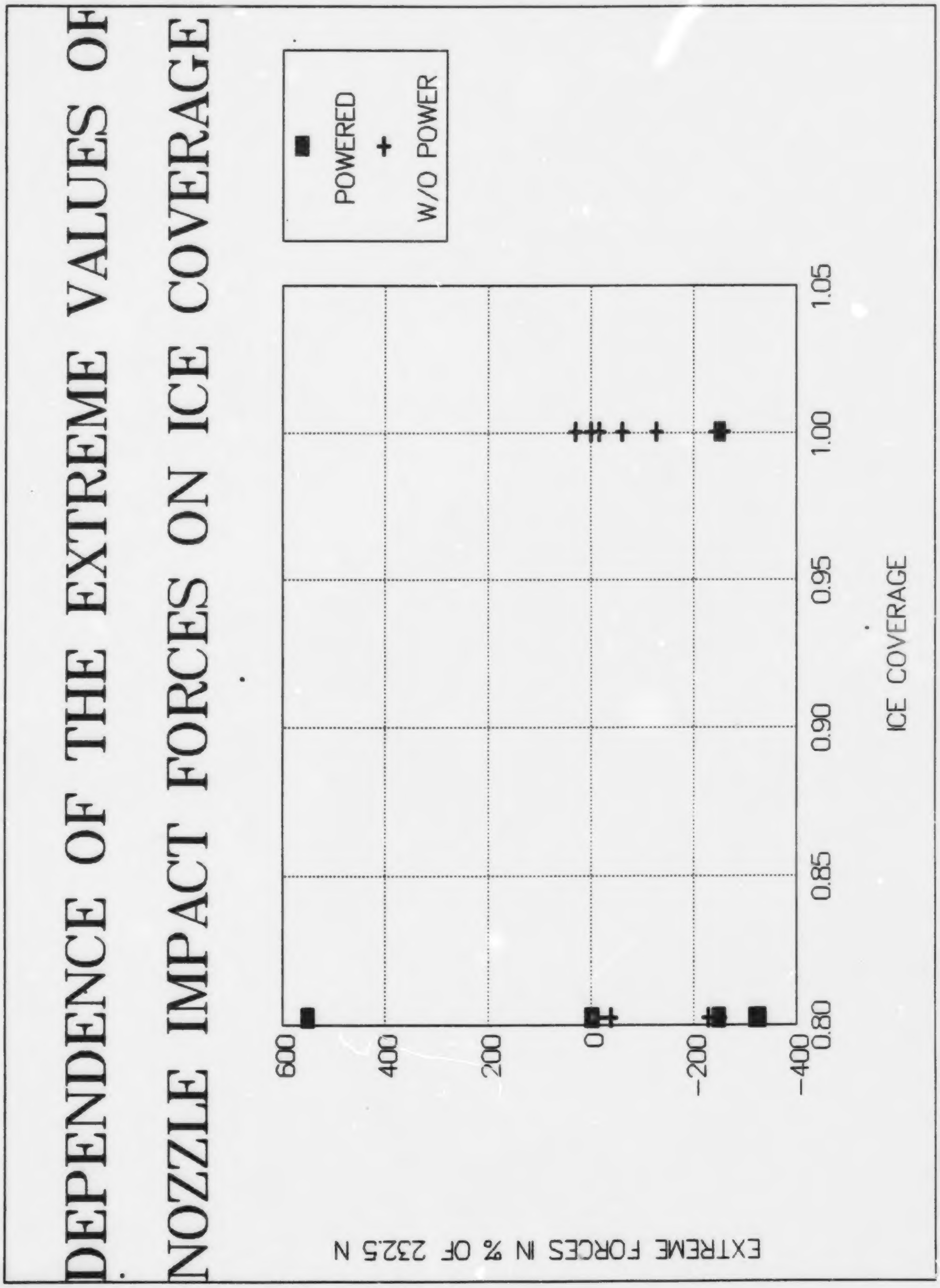
DEPENDENCE OF THE EXTREME VALUES OF TORQUE AND THRUST ON MODEL SPEED





DEPENDENCE OF THE EXTREME VALUES OF NOZZLE IMPACT FORCES ON MODEL SPEED

Figure 15.4



DEPENDENCE OF THE EXTREME VALUES OF NOZZLE IMPACT FORCES ON ICE COVERAGE

DEPENDENCE OF THE EXTREME VALUES OF NOZZLE IMPACT FORCES ON MODEL DRAFT

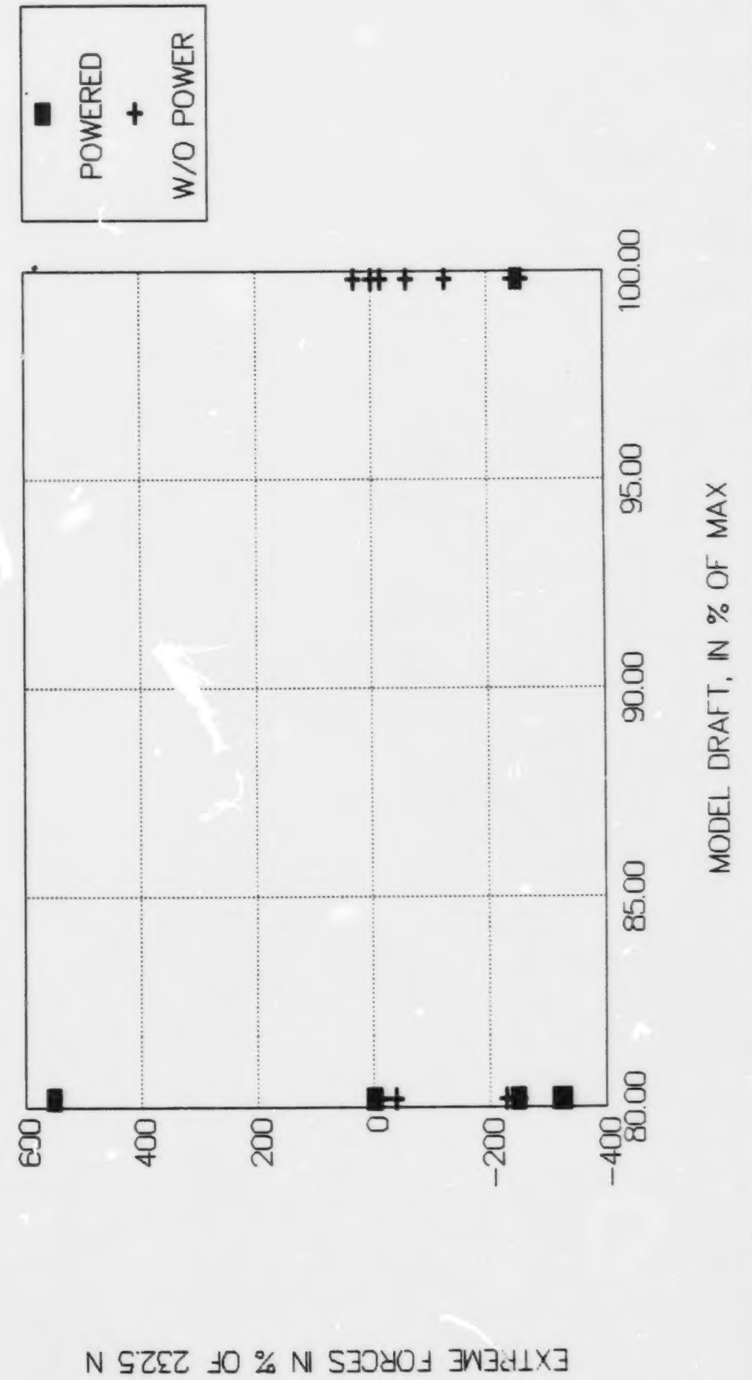


Figure 15.6

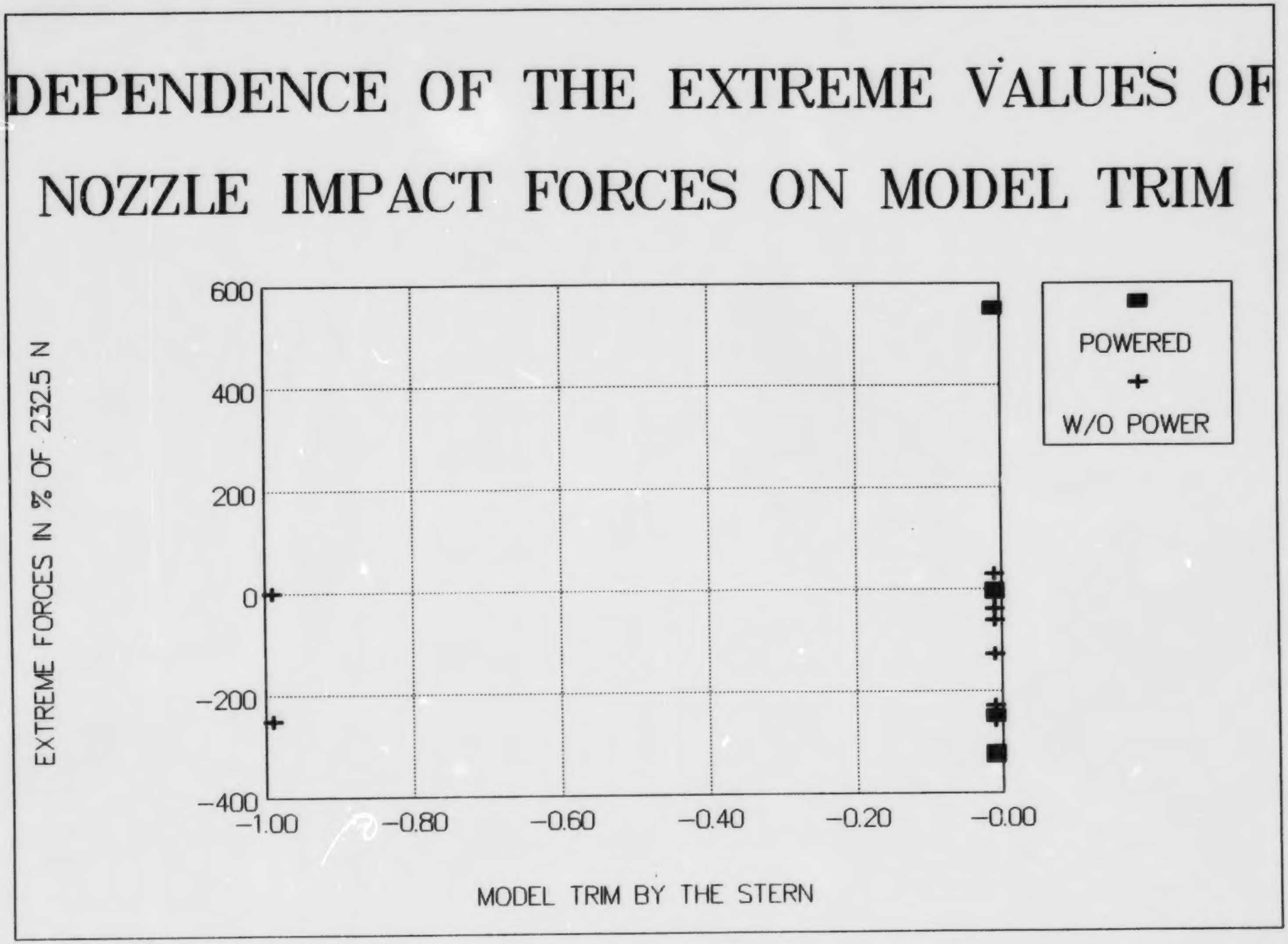

DEPENDENCE OF THE EXTREME VALUES OF NOZZLE IMPACT FORCES ON MODEL TRIM
600
400
200
0
−200
−400
−1.00
−0.80
−0.60
−0.40
−0.20
−0.00
EXTREME FORCES IN % OF 232.5 N
MODEL TRIM BY THE STERN
■ POWERED
+ W/O POWER

Figure 15.7

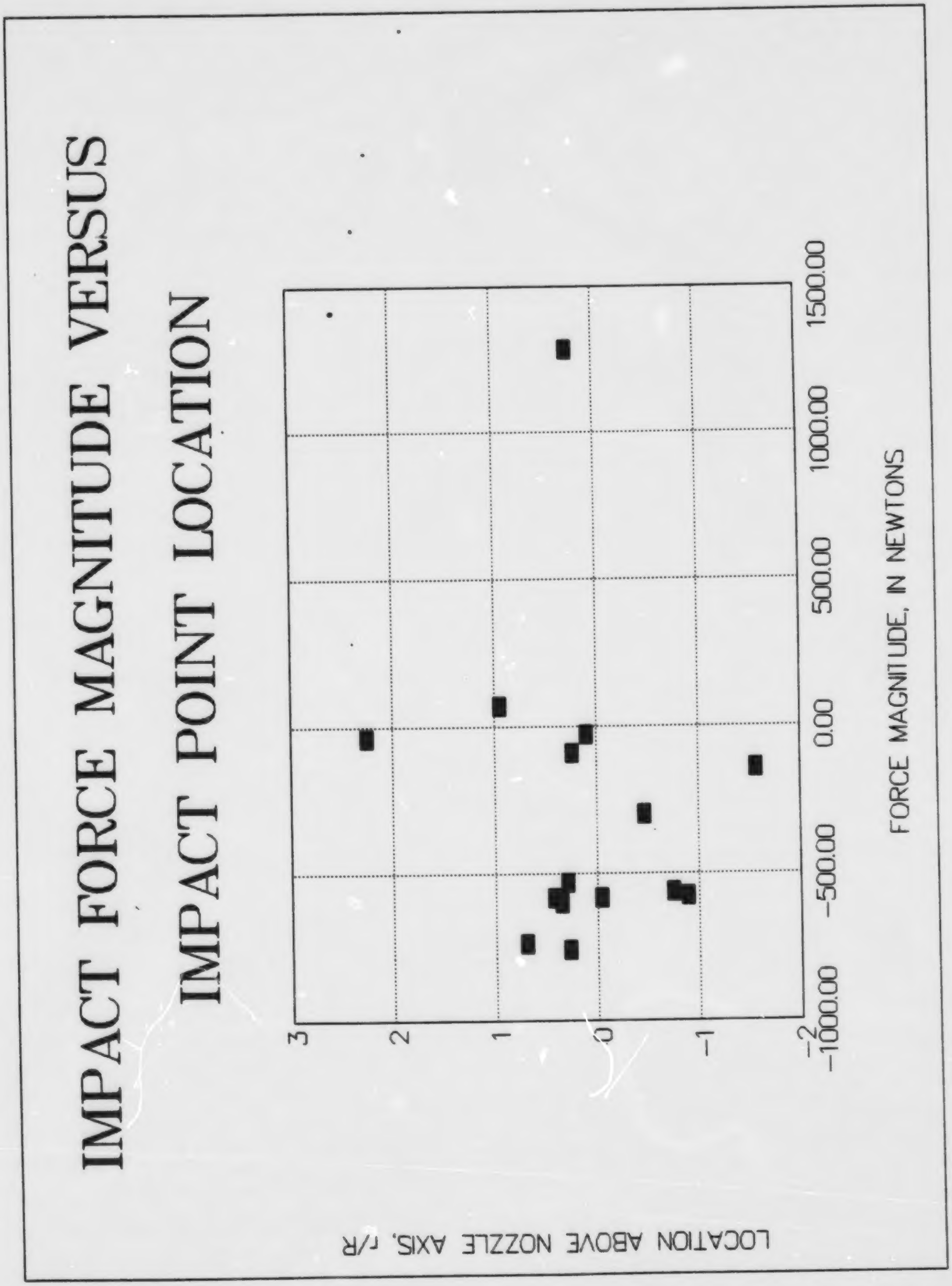
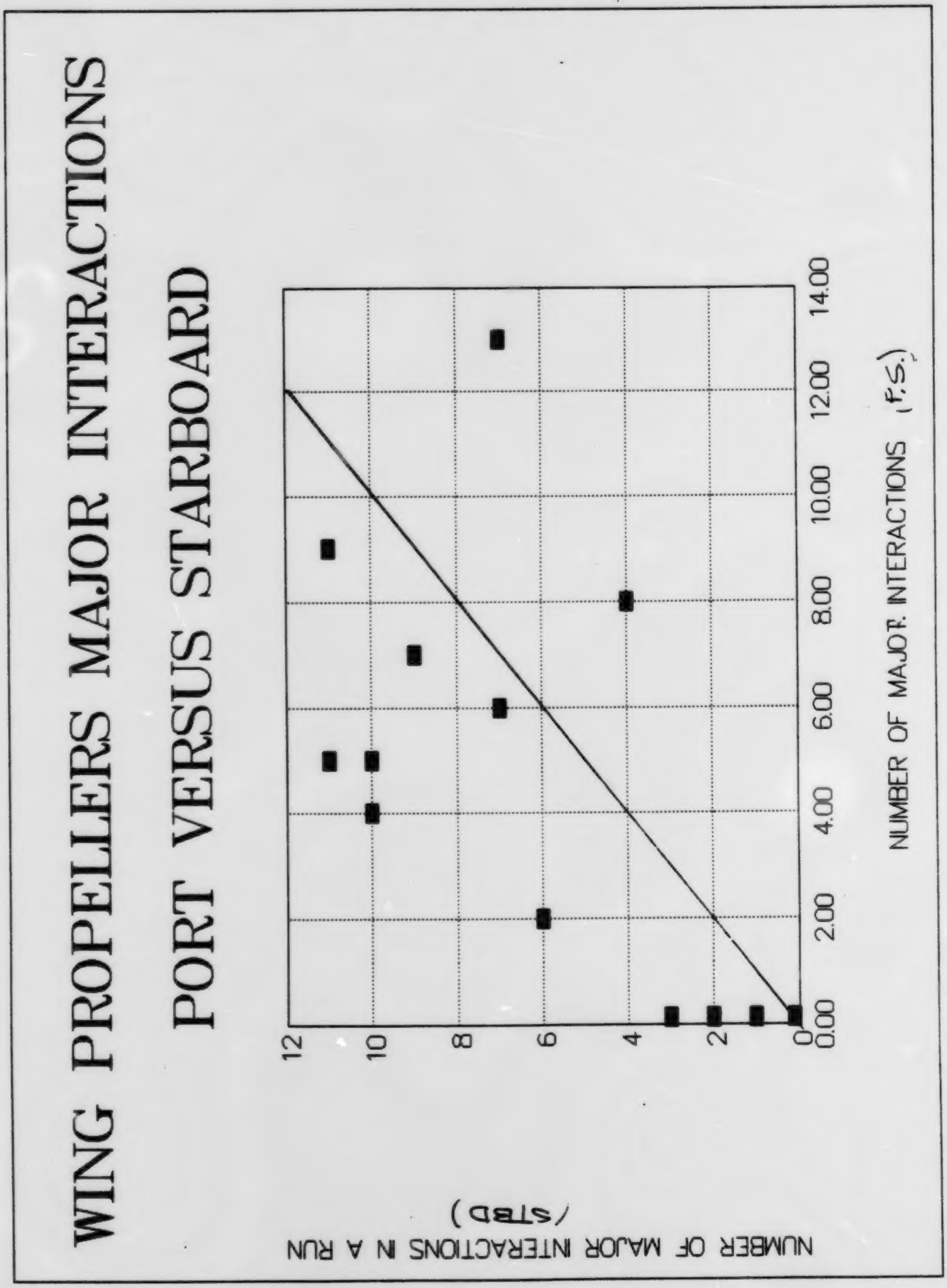

IMPACT FORCE MAGNITUDE VERSUS IMPACT POINT LOCATION

TABLE 15.3

NUMBER OF MAJOR INTERACTION WITH ICE BLOCKS

| TEST NUMBER | CENTER SHAFT | PORT SHAFT | STARBOARD SHAFT | CNTR POWERED P+S/2 | NO POWER |
|---|---|---|---|---|---|
| | NUMBER OF INTERACTIONS IN A RUN | | | | |
| 1 | 1 | 9 | 11 | 10 | |
| 2 | 1 | 0 | 3 | 1.5 | |
| 3 | 6 | 13 | 7 | 10 | |
| 5 | 0 | 0 | 1 | 0.5 | |
| 6 | | 5 | 10 | 7.5 | |
| 7 | | 0 | 2 | | 1 |
| 9 | | 7 | 9 | | 8 |
| 10 | | 0 | 0 | | 0 |
| 11 | | 8 | 4 | | 6 |
| 12 | | 0 | 0 | | 0 |
| 13 | | 4 | 10 | | 7 |
| 14 | | 0 | 0 | | 0 |
| 15 | | 5 | 10 | | 7.5 |
| 16 | | 0 | 0 | | 0 |
| 17 | | 0 | 0 | | 0 |
| 18 | | 0 | 0 | | 0 |
| 19 | | 2 | 6 | | 4 |
| 21 | | 0 | 0 | | 0 |
| 22 | | 5 | 11 | | 8 |
| 23 | | 0 | 0 | | 0 |
| 24 | | 0 | 0 | | 0 |
| 25 | | 0 | 0 | | 0 |
| 26 | | 0 | 0 | | 0 |
| 27 | | 6 | 7 | | 6.5 |
| TOT | 8.00 | 64.00 | 91.00 | | |
| MAX | 6.00 | 13.00 | 11.00 | | |
| AVGE | 2.00 | 2.67 | 3.79 | | |

Figure 15.8


WING PROPELLERS MAJOR INTERACTIONS
PORT VERSUS STARBOARD
NUMBER OF MAJOR INTERACTIONS IN A RUN
(STBD)
0
2
4
6
8
10
12
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NUMBER OF MAJOR INTERACTIONS (P.S.)

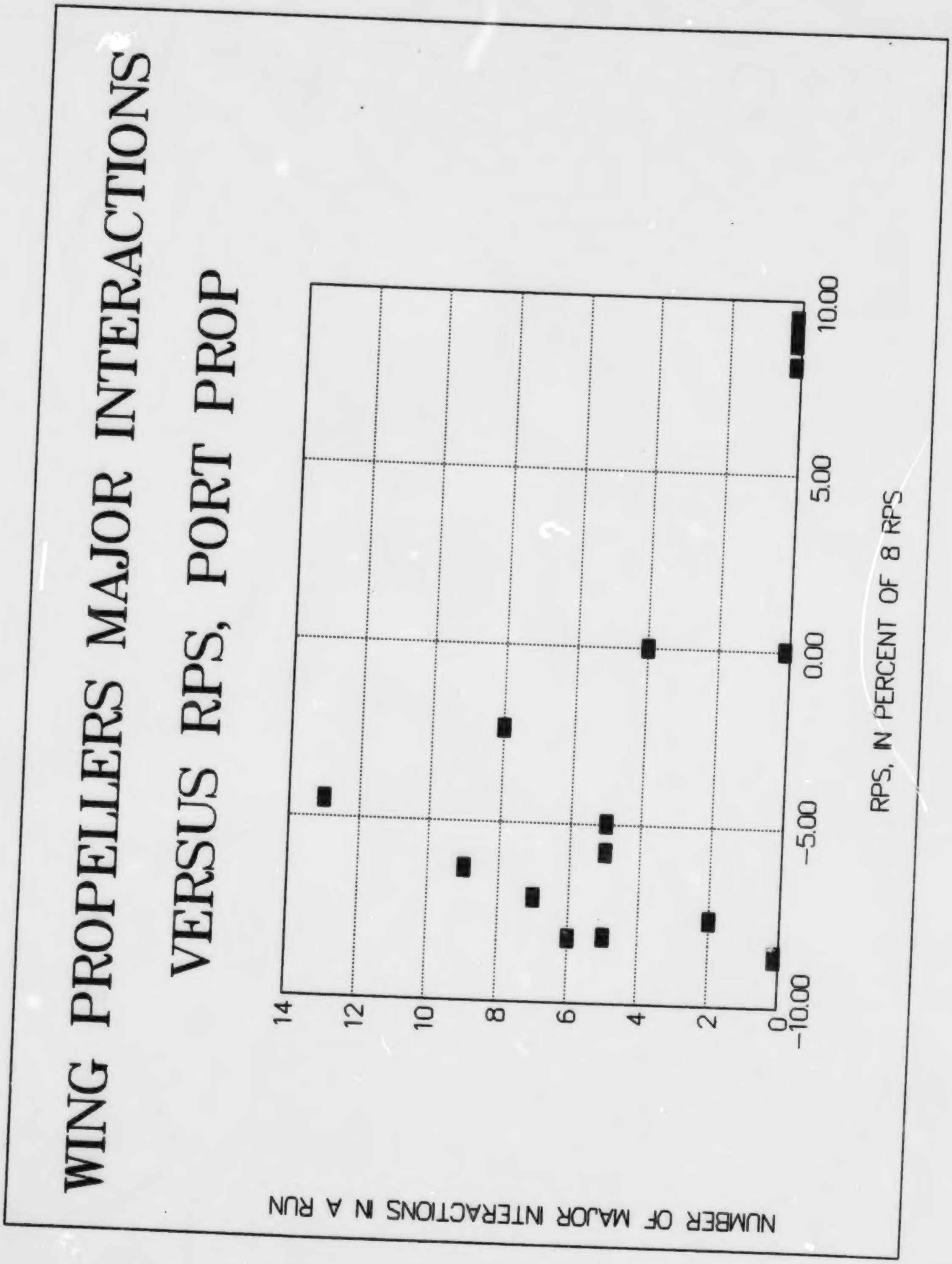
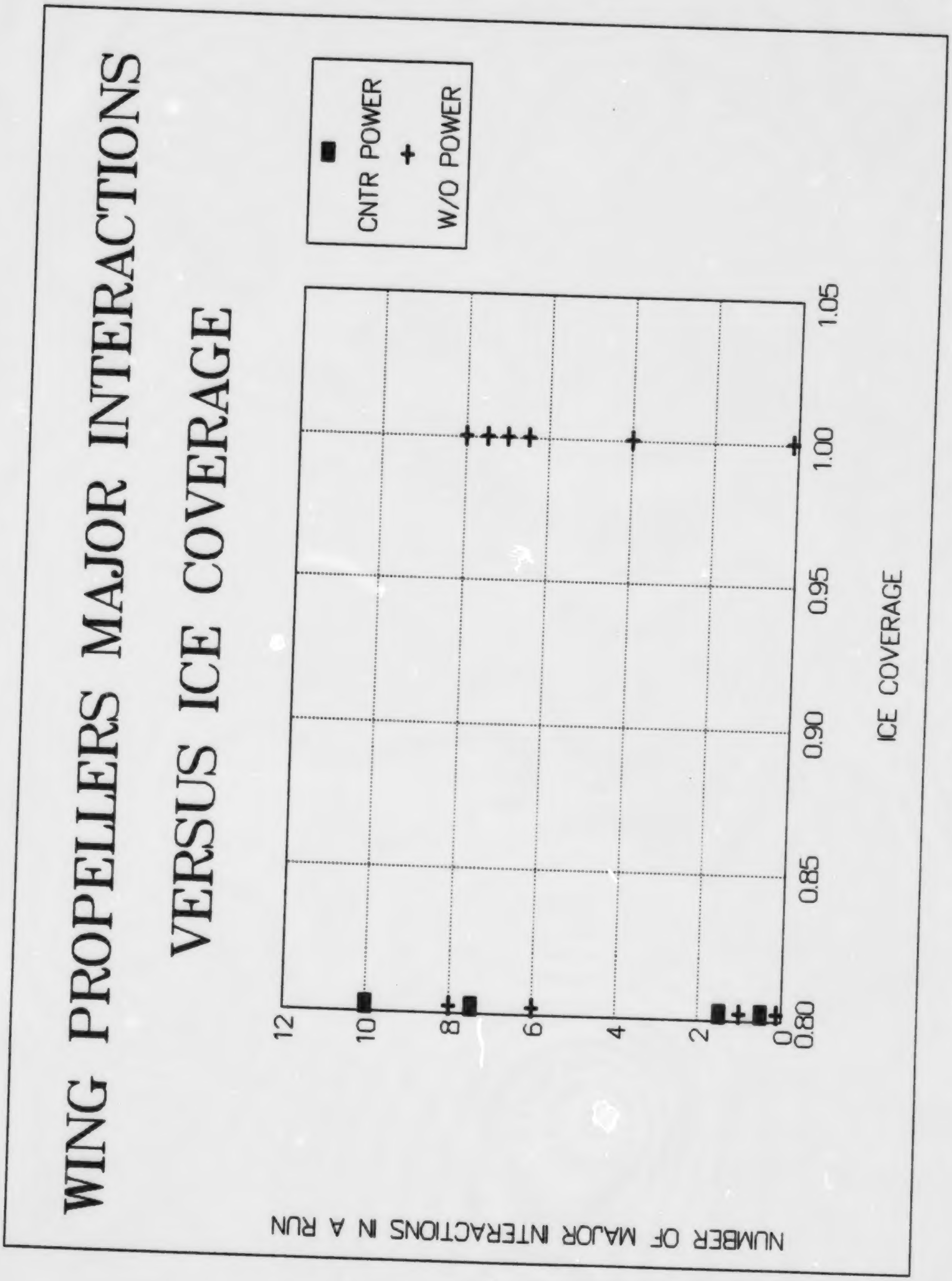

WING PROPELLERS MAJOR INTERACTIONS
VERSUS RPS, PORT PROP
NUMBER OF MAJOR INTERACTIONS IN A RUN
0
2
4
6
8
10
12
14
-10.00
-5.00
0.00
5.00
10.00
RPS, IN PERCENT OF 8 RPS

Figure 15.10



WING PROPELLERS MAJOR INTERACTIONS VERSUS ICE COVERAGE

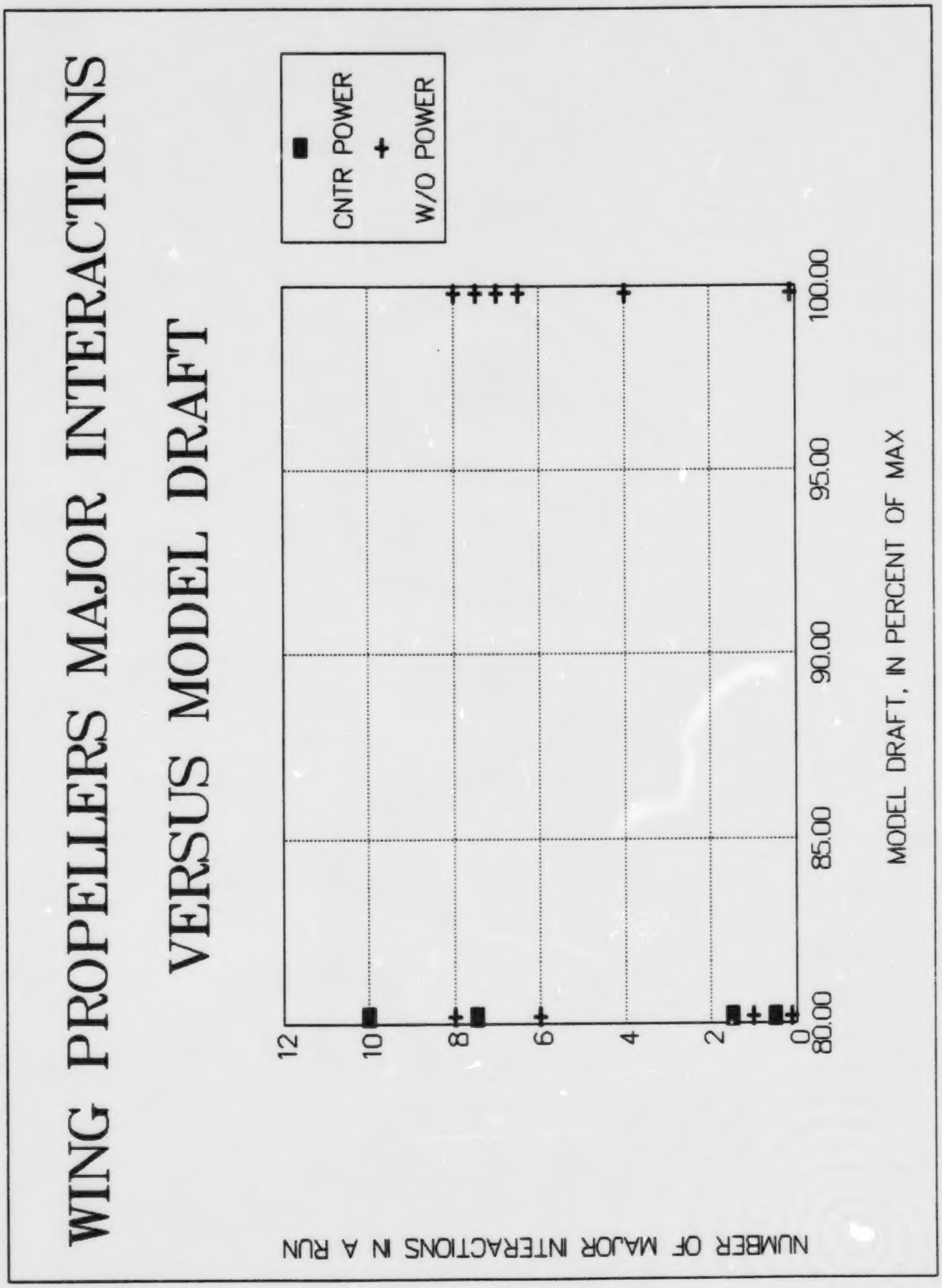
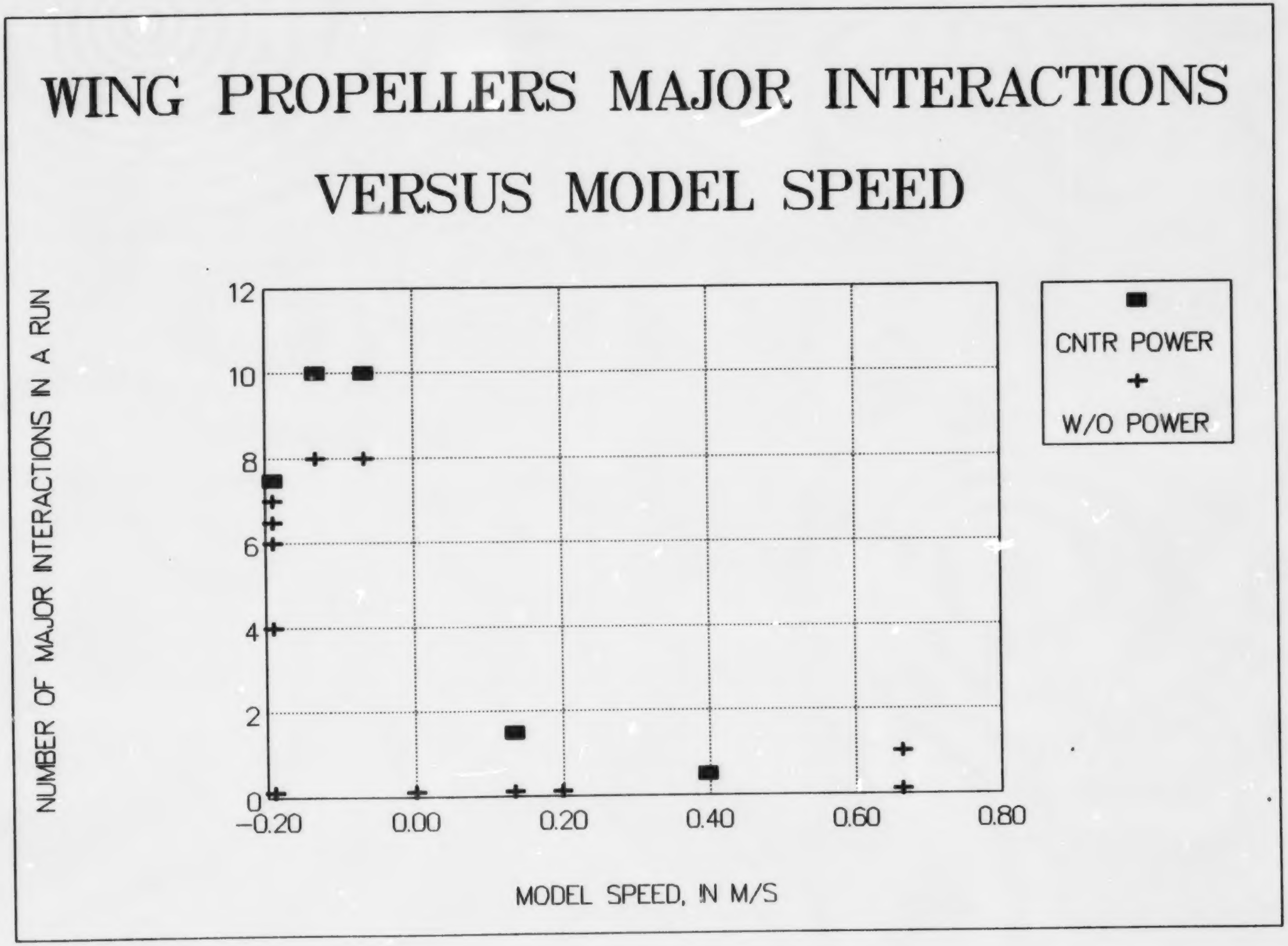

WING PROPELLERS MAJOR INTERACTIONS
VERSUS MODEL DRAFT
CNTR POWER
W/O POWER
NUMBER OF MAJOR INTERACTIONS IN A RUN
0
2
4
6
8
10
12
80.00
85.00
90.00
95.00
100.00
MODEL DRAFT, IN PERCENT OF MAX

Figure 15.12



WING PROPELLERS MAJOR INTERACTIONS VERSUS MODEL SPEED

Figure 15.13a

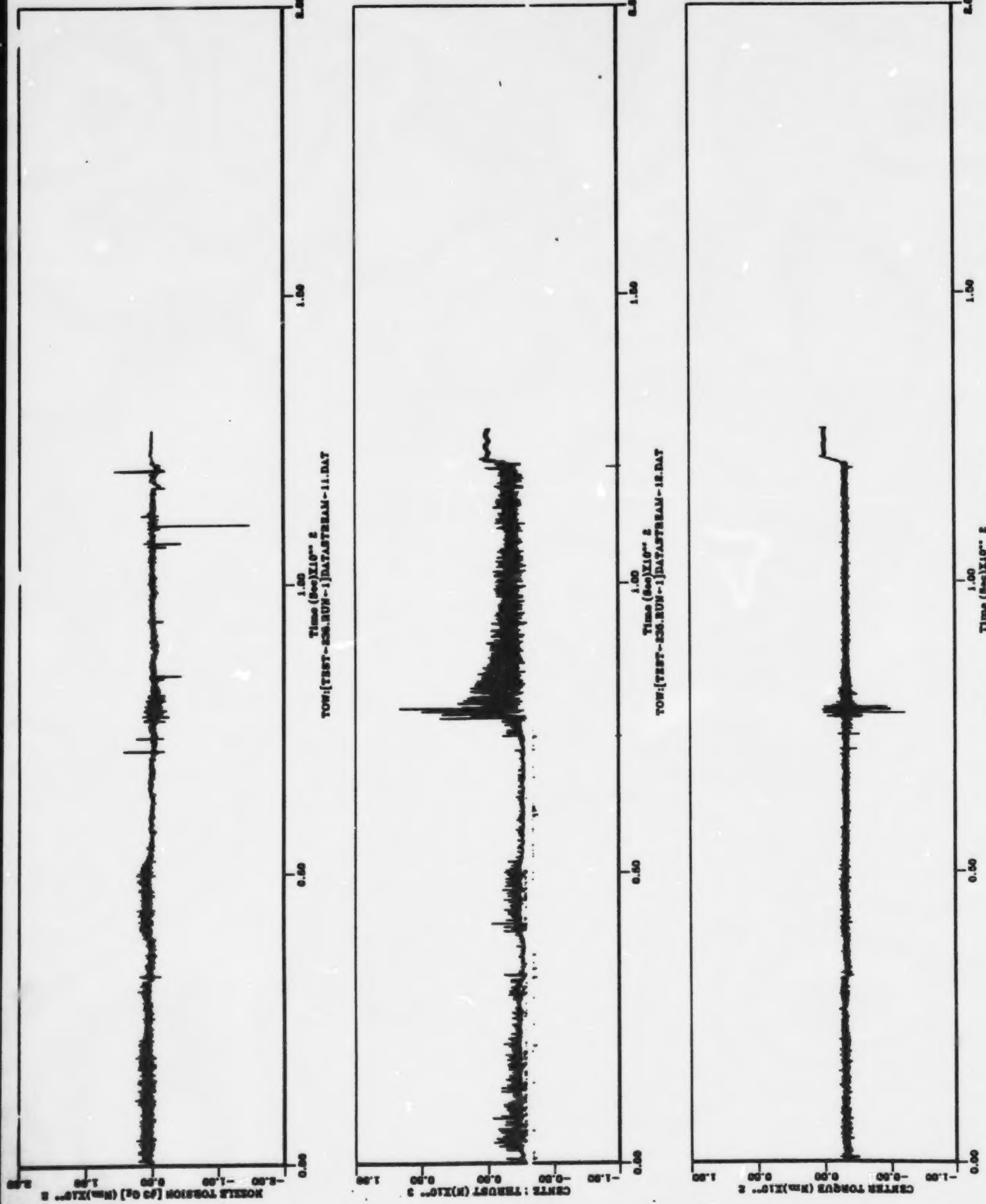


Figure 15.13b

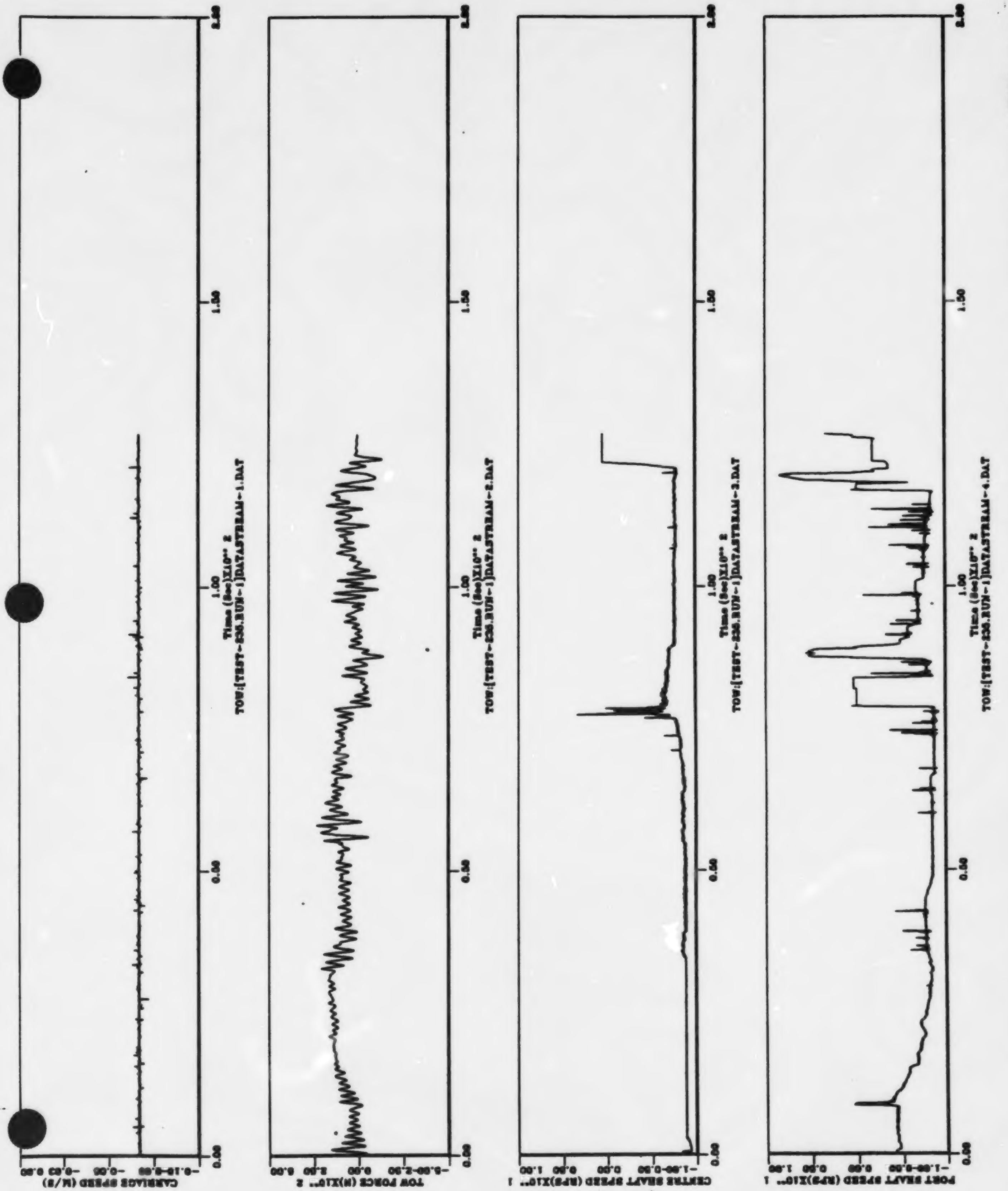


Figure 15.13c

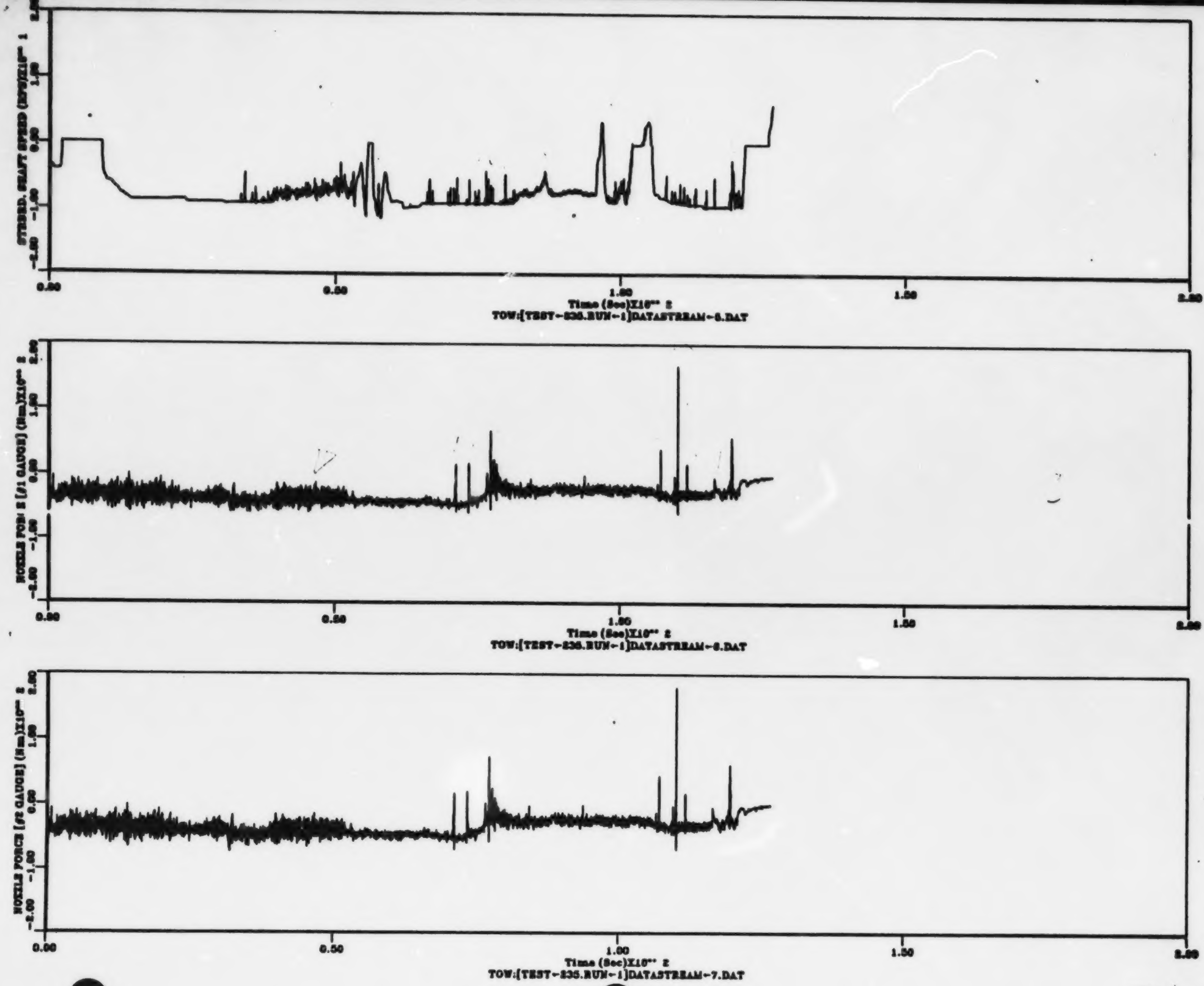
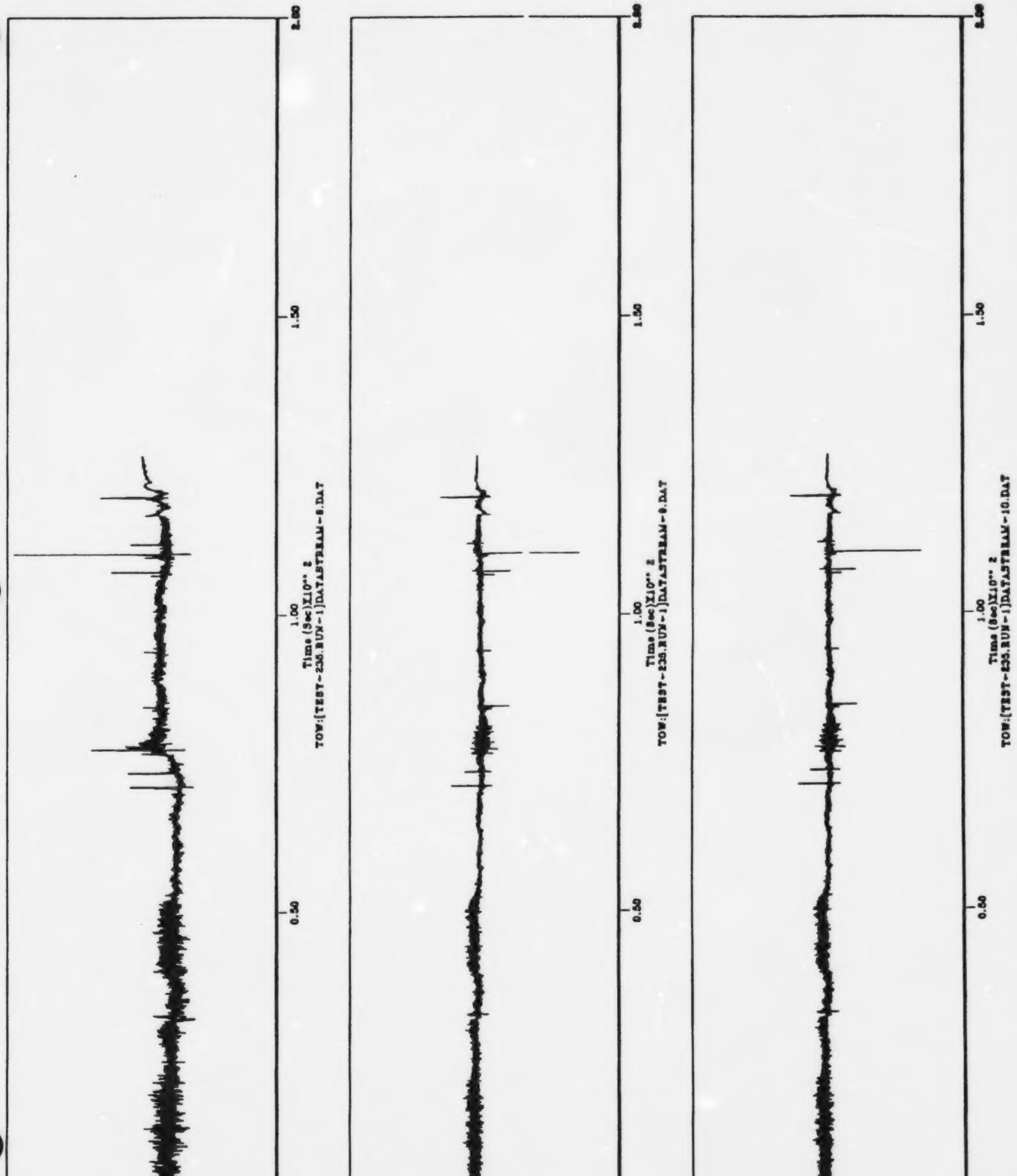


Figure 15.13d



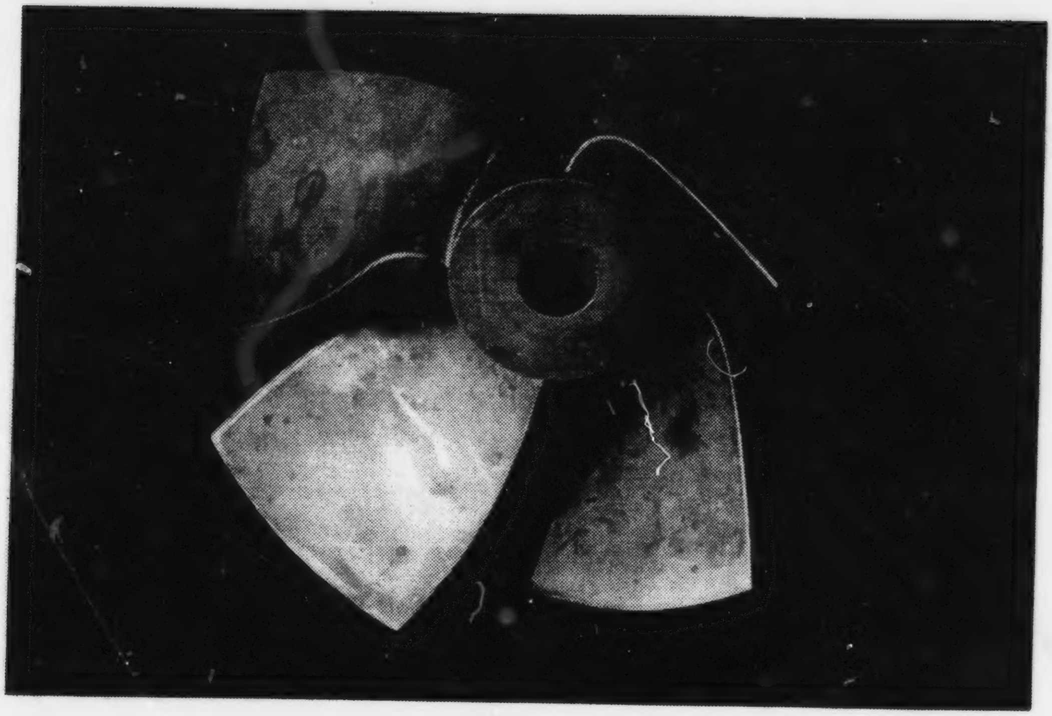


Photo 15.15 - Damaged Propeller Configuration

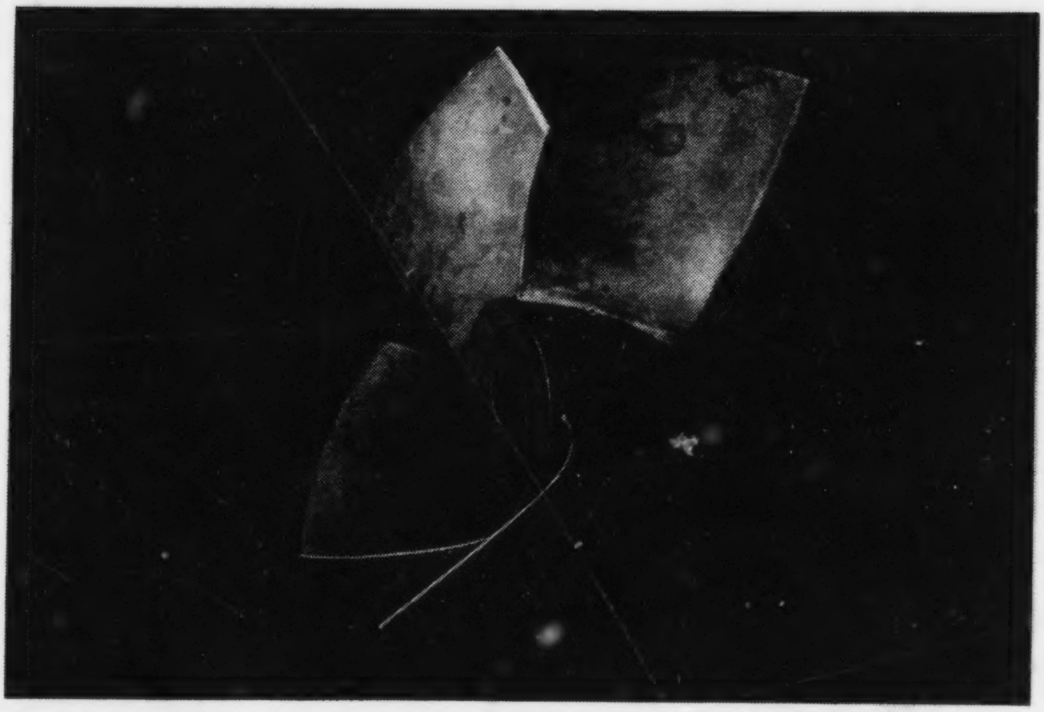


Photo 15.16 - Damaged Propeller Configuration

## *16. CONCLUSIONS*

*The detailed conclusions derived from this testing programme are contained at the end of each chapter. Here, we give the summary of the main conclusions and findings.*

### ***FLOAT UP TESTS***

1. *Emergence time is proportional to the depth.*
2. *Emerging ice blocks attain quickly the limiting speed of ascent which is a constant for the block.*
3. *The critical (limiting) speed* ***Vcr*** *is dependent on:*

   *ice block thickness* ***Hi,***
   *ratio of ice density to water density* ***row/roi***
   *drag coefficient* ***cr.***
   *gravity constant* ***g***

   $$Vcr = (2*g*Hi*(row/roi -1)/cr)^{0.5} \ldots\ldots\ldots\ldots 16.1$$

4. *Free ice float-up motion is well represented by the analytical formulations given in the text.*
5. *Motions of ice blocks are oscillatory, but stable.*
6. *Heavier ice blocks emerge faster than the light ones. For the sizes tested and depth of 1.6m, we have:*

   $$\text{emergence time} = 14.8 - 1.898 * \text{block weight} \ldots\ldots\ldots\ldots 16.2$$

7. *Edge-up emergence is faster than the flat face up.*
8. *Distance travelled by an emerging ice block can be approximated by a formula:*

   $$z(t) = a + Vcr * t \ldots\ldots\ldots\ldots 16.3$$

   *where* ***a*** *is a constant particular to the specifics of an ice block, and* ***Vcr*** *is the limiting velocity.*

9. *Effective added mass coefficients of ice blocks are approx 4.*
10. *Effective drag coefficients of ice blocks decrease with an increase of ice block thickness.*
11. *Float-up time of an ice block* ***near the wall*** *is approximately* ***4 times longer*** *than the free float-up time.*

12. *Float-up times of ice blocks released from the bottom of the model* ***decrease with an increase of block's weight.***

13. *For the block tested, average float-up time from the bottom of the model was 2 sec. The longest time was at the midbody position.*

14. *For suddenly accelerated ice blocks, the average speed of travel was* ***inversely proportional to an initial acceleration.***

15. ***There exists a critical speed,*** *beyond which an ice block's free motion becomes unstable and overall speed slows down.*

16. *In order to attain large distances when pushing ice blocks away,* ***gentle accelerations below the critical speed*** *are needed, not sudden large magnitude impulses.*

## FRICTION TESTS

* *Wax blocks used in this project have frictional properties very* ***compatible with the full scale low pressure measurements*** *of friction ice/ INERTA 160.*

* *Method of measurements used, which reflects the actual physics of interaction between the submerged ice blocks and the hull,* ***is convenient and give consistent results.***

* *Friction factor of wax/hull surface is* ***0.24,*** *and varies slightly with the surface finish and condition.*

* *Friction factor wax/hull is* ***not dependent on the weight*** *of the ice blocks. A slight decrease of the friction factor was observed only for a wet wax on wax condition, which simulates the friction between the blocks.*

* *Water presence* ***increases the friction factor from 0.21 to 0.28*** *for wax/wax condition.*

* *Friction between wax and hull is smaller than the friction between the blocks (****0.24 versus 0.28****).*

## WATERJET TESTS

### General

1. *Test method was successful and yielded useful information about the thrust of submerged jets.*

   *Maximum thrust measured was* ***26.4 N***

*Maximum power developed by the jet was **440 Watts.***

2. *Froude's Scaling Laws can be applied to extrapolate the model tests results to the full scale applications.*

   *Thrust of the jet scales up with (la)^3*

   *Power of the jet scales up with (la)^3.5*

**Analytical computations**

1. *Calculations of the jet force by means of adding of static and dynamic components gives good results.*

2. *Calculations of the force using the jet force formula is a good approximation in the whole range tested.*

   ***F = 1025 * V^2 * orifice area**.............16.4*
   *(all dimensions in SI units)*

3. *Force on the target can be computed in a first approximation by using the power of the jet as follows:*

   ***F = C * (4 *(Jet power)^2 * ro * Orif area)^1/3**......16.5*

   *where C is the distance coefficient computed from:*

   ***C = 1.03 - 0.3343 * distance**..............16.6*

   *Above formula is valid only for the range of powers tested.*

**Maximum force/distance**

*The force on the target **drops proportionately** with the distance from the target.*

*The drop is **small for medium and large size nozzles** and large for small size nozzle. Drop is linear, for the range tested.*

**Maximum force/nozzle area**

*Increasing the nozzle area increases the force until a cut off is achieved due to the limitations of the system supply.*

**Maximum force/ pressure**

*The maximum force on the target increases nearly proportionately with the pressure in the system.*

**Maximum force/ medium**

*The maximum force in water is larger than the maximum force in air.*

### *Efficacy of the system*

*Nozzles used in these tests were of simple design, hydraulically comparable to the sharp edge opening in a wall of a tank.*

*The average (for all the tests) thrust/power efficacy coefficient of the jet increases linearly with the increase of nozzle aperture area.*

*For the nozzle tested, average efficacy was* ***6.15 KG/HP*** *for the medium nozzle.*

### *OVERLOAD TESTS RESULTS*

1. *The centerline nozzle and propeller develop* ***11.4 kG/HP*** *(full scale) which is* ***more than 35% higher*** *than the corresponding open propeller, in bollard condition.*

2. *Thrust astern in the bollard astern condition is approximately equal to the thrust ahead of the system, in ahead bollard condition, for the same RPS.*

3. *High astern thrust of the system (****70% of the bollard ahead****) is maintained even at* ***6 knots astern*** *speed.*

4. *The above* ***findings confirm fully the results*** *of the investigations contained in the Reference 1.*

5. ***Nozzle develops more thrust than the propeller*** *at bollard ahead condition.*

6. *The location of the nozzle thrust vector changes with the change of nozzle load, especially the vertical one.*

7. *The location of the thrust vector is predominantly below the nozzle axis.*

8. *Centerline nozzle/propeller system delivers* ***more than 1/3*** *of the total three shafts thrust, for the constant RPS, for all conditions tested (from 40% to 60% of the total).*

9. *The thrust deduction factor is* ***0.23*** *for the centerline nozzle and propeller system, in the ahead bollard condition and with the wing propellers stopped.*

10. *For the astern bollard condition, the thrust deduction factor is* ***0.32****.*

## *THRUST CHANGE AS A RESULT OF WING PROPELLER INTERFERENCE*

1. *There is sufficient data to conclude that the wing propellers* ***cause considerable disturbance*** *in the working of the centerline propeller and nozzle.*

2. *For the full power ahead, a* ***considerable gain*** *in the nozzle can be anticipated, by an analogy with the axial pumps working in series. For the astern condition,* ***severe penalty*** *in the centerline thrust may take place.*

## *BLOCKAGE TEST RESULTS*

### *BLOCKAGE CHARACTERISTICS*

1. *Blockage leads to the following (for the constant RPS):*

   *increase of the shaft thrust,*
   *increase of the shaft torque,*
   *decrease of the nozzle thrust,*
   *decrease of the total thrust,*
   *increase of the power absorbed,*
   *decrease of the tow rope pull,*
   *increased level of vibration of the nozzle, propeller and shaftline.*

2. *Nozzle blockage corresponds hydrodynamically to the condition when the vessel is moving at a certain speed in open water but the propeller works in* ***a strong wake,*** *that is at* ***much lower speed of advance than the ship (even negative speed of advance)****, and the propeller rotates in the forward direction.*

### *PERFORMANCE OF PROPELLER/NOZZLE IN BLOCKED CONDITION*

3. *The largest* ***nozzle thrust drop*** *was recorded from the* ***+65%*** *in the non-blocked condition to* ***-50%*** *of the total system thrust at the bollard when the middle part of the nozzle was blocked and all three shafts were working. A slight increase of the nozzle thrust was noted when the device was placed some 10cm in front of the nozzle mouth.*

4. *The performance indicators, like tow pull/power developed or the total system thrust/power developed dropped with introduction of blockage from approximately* ***100% to 25%*** *in the* ***middle blocked condition.***

5. ***The most severe blockage condition****, in terms of the tow pull/power delivered, occurred when the* ***middle part*** *of the*

*nozzle was blocked. The least severe was when the device was placed 10cm ahead of the nozzle. In terms of the tow pull/ power delivered the following is the order of performance:*

*TABLE 16.1*

*Summary of the system performance*

| PERFORMANCE | CONDITION<br>BOLLARD AHEAD | BOLLARD ASTERN | AREA BLOCKED |
|---|---|---|---|
| best | no blockage | no blockage | 0% |
| | 10 cm distance | | |
| | top blocked | top blocked | 20% |
| | bottom blocked | bottom blocked | 23% |
| | 5 cm distance | | |
| worst | middle blocked | middle blocked | 47% |

6. ***Wing shafts increase blockage severity,*** *by providing an additional drag force on the blocking piece, which translates into the lower overall nozzle thrust.*

7. *Vessel speed decreases the total thrust/power delivered ratio substantially in the blocked condition.*

8. ***In the astern condition the effects of the blockage were more moderate*** *than in the ahead condition.*

*SUCTION FORCES*

8. *Suction forces on the block placed ahead of the nozzle mouth* ***depend strongly on the propeller thrust.***

9. *The suction forces decrease with the increase of speed.*

10. *The suction forces at a piece placed 5 cm ahead of the nozzle are of* ***the same magnitude as the propeller thrust.***

11. *The forces* ***decrease rapidly with the increase of the distance from the nozzle****. Doubling the distance cuts the suction force to approximately 1/3.*

12. *In the blocked condition, the* ***nozzle develops a small fraction*** *of the propeller thrust, and the* ***nozzle thrust is directed aft*** *(including the suction force).*

13. *The suction force on the blocking piece at 90% of the power, placed 5 cm ahead of the nozzle mouth, is of the same magnitude as the* ***drag on that piece at a velocity of 11*** *knots.*

## *VIBRATION LEVELS*

14. *The thrust, torque and nozzle* ***vibration levels are*** *significantly* ***increased*** *from the non-blocked condition.*

15. *Shaft longitudinal vibrations are not related to shaft torsional vibrations.*

16. *Nozzle axial vibrations are not coupled with the nozzle torsional vibrations.*

## ***ANALYTICAL CONSIDERATIONS***

1. *The amount of ice in the stern area (VL remain) is proportional to the velocity (V) of the ship:*

$$\textbf{VL remain} = c1 * V - c2 \qquad 16.7$$

*where c1 and c2 are the proportionality constants.*

2. ***There exists a certain velocity below which there is no ice*** *in the stern and propeller area.*

3. *Propeller/nozzle* ***suction pressure is proportional to the thrust of the system.*** *This relationship was confirmed during the blockage tests.*

4. *The* ***suction pressure drops rapidly with the increase of the vessel speed.*** *This was also confirmed by the tests.*

5. ***Suction of propeller/nozzle system can not pull the free floating ice blocks down.*** *This would require the air suction from the surface to occur first.*

6. ***The highest drop of pressure is above the propellers.***

7. *Several indicators can be used in order to estimate the amount of ice flow into the propeller area, in the ahead motion. Among them:*

*beam / girth length*
*waterplane area / wetted surface area*

$$B * HP / (LOA * T) \qquad 16.8$$

*where:*

*B is the ships beam,*
*LOA is the ship's length overall*
*T is ship's draft*
*HP is the power delivered to the propellers*

*LSSL has a moderate value of this indicator (**643**), the highest* *being that for the Polar Star class ship (**1313**) and the lowest being that for the MV Arctic (**106**).*

8. *The **velocity of submergence of ice is large (60%** of the advance velocity) at the bow and at the stern of the LSSL. This means that ice blocks "slap" the hull when they are being submerged, and that the stern pushes ice blocks down vigorously into the propeller area.*

9. *Much improvement can be made to the stern design of LSSL.*

## ***TESTS IN ICE - FIRST SERIES***

### *PERFORMANCE OF THE NOZZLE/PROPELLER SYSTEM*

1. *The performance of the centerline propeller and nozzle, as well that of the wing propellers **was inferior** when compared to the performance **in ice free waters**. One reason for it was a necessity to reverse the RPS when a heavy block/propeller interaction occurred.*

### *MAJOR INTERACTIONS*

2. *The port shaft saw least of major interactions, **the starboard shaft the most**, and the center shaft the average between the two.*

3. ***Ahead mode of operations saw 10 times less interactions per meter travelled than the astern mode.***

4. *The frequency of major interactions is proportional to ship speed, in both ahead and astern modes of operations.*

5. *In both modes of operations, there is a **certain minimum speed, below which no interactions** take place between the propellers and ice. The number of interactions per second can be expressed as:*

$$NOMI = A + B * V \quad ......................... 16.9$$

*where A and B are constants and V is the ship speed.*

### *IMPACTS ON THE NOZZLE*

6. *Major impacts sharing between the shafts is speed independent.*

7. *The **number of impacts on the nozzle is power independent.***

8. *The **reversed RPS lead to the high number of impacts** of the nozzle.*

9. *The **reduced draft resulted in the increase** of the number of*

*interactions.*

10. *Within the range tested, ice coverage is not correlated with the number of interactions.*

*IMPACT FORCES*

11. *The* ***largest impact force on the nozzle was 645% (1,500 N)*** *of the system's bollard thrust. It occurred in the astern mode of operation, at a reduced draft.*

12. ***All large magnitude impacts occurred when ship was going astern.***

13. *Lighter draft of the vessel leads to the higher magnitude forces.*

14. *There is no clear correlation between the magnitude of the impact forces and ice coverage.*

15. ***High impact forces are linked with the low average power levels.***

16. *There is no strong correlation between the mean thrust and the maximum impact force level.*

17. *Above considerations lead to the conclusions that the frequency and magnitude of interaction forces* ***are geometry related, that is they depend on the hull and shaft configurations*** *and the proximity of the ice field,* ***not on the suction ability of the propulsors.***

18. *Low speeds generate highest impact forces.*

*STATISTICS OF THE SHAFT TORQUE AND THRUST*

19. *The maximum and minimum values of the torques recorded were proportional to the mean values developed during the runs.*

20. *The same applies to the thrust, except in the astern mode, where there is a weak correlation between the maximum and mean values.*

*ICE FLOW*

*Ahead motion*

21. *The* ***bow clears the ice pieces effectively****. At station 12 there is no ice in the bottom region.*

22. *The deepest submergence of the blocks reaches the region of the ice knife.*

23. *Emergence of ice blocks is* ***linked to the tumbling of the ice***

*__block envelope__ surrounding the hull.*

24. *At a deep draft, there is little wing propeller/ice block interaction, as __most of ice pieces pass over the propellers.__*

25. *The ice pieces are sucked in by the stern, rather than the propellers, and they come from the sides of the ship not the bottom.*

Astern motion

26. *In this mode of operations, ice is pushed down into the propellers by the stern.*

27. *Ice blocks wedge between the hull and:*

    ***rudder post,***
    ***nozzle upper surface***
    ***wing bossing skegs.***

28. *The __wedging__ of the blocks on the wing propeller bossings is __very pronounced__ and leads to the creation of frequent pile-ups in the stern area and severe ice/propeller interactions. This wedging is partially due to the __inward turning propellers__ (in this mode of operations).*

29. ***Wing propellers rotate inward in the astern mode of operations pushing ice downward along the hull**. Outward rotation would result in less interactions and lower forces.*

30. *Lower draft leads to the __massive presence of ice blocks in__ the __stern/propeller area.__*

31. *The stern of the ship piles up the free floating ice blocks and pushes those in front of it.*

*NOZZLE/ICE BLOCKS INTERACTIONS*

32. *The following are the modes of interactions recorded during the tests:*

    *single impacts*
    *interactions with the nozzle support*
    *blockages*
    *milling*
    *indirect interaction*

    *Indirect interactions are the result of the wing propellers reversals due to the milling of ice blocks which results in a significant disturbance of the hydrodynamic condition of the nozzle/propeller system*

33. ***Only two cases of blockage** of the nozzle were recorded during this test series:*

*one in the astern operations, and*
*one at the reduced draft ahead, speed 10 knots.*

*This very limited amount of the blockage is due to:*

*good ice clearing capability of the bow*
*wing propellers and their wash providing an effective force against ice blocks moving around the nozzle*
*deep draft of the vessel.*

## ICE BLOCKS/HULL INTERACTION

34. *The hull of the vessel moving in a broken ice field compresses and moves the blocks ahead of itself creating an artificial high density zone in the bow or stern area.*

35. *Ice blocks are submerged when the frame angles (measured to horizontal) are small, and are pushed aside when the frame angles are large.*

36. *There is a* ***high pressure area on the bow*** *right above the ice knife (station 17)› This area extends from the stem to station 16 and from the above waterline to the 60% of the vessel draft.*

37. *All appendages at the stern show large number of heavy interactions with the blocks.*

38. ***Bottom of the nozzle shows the evidence of interactions*** *with the blocks. So does the bottom of the rudder.*
    *This is most likely due to the fact that the wings propellers* ***kick ice blocks down below the keel*** *when operating in the astern mode.*

39. *Wing propeller bossing skegs show pronounced marks of ice blocks sliding along.*

40. ***Stern area shows the traces of much more heavy interactions with blocks than the bow area.***

## OVERLOAD TESTS WITH THE DEFLECTOR

1. ***There is no measurable difference in the propulsor efficacy*** *at 100% RPS in the bollard and ahead condition with and without the deflector.*

2. *At lower powers developed, the deflector leads to the* ***lowering of the propulsor efficacy in the ahead and astern*** *condition.*

## TESTS IN ICE WITH DEFLECTOR

1. *Maximum impact forces on the nozzle are higher when the nozzle propeller operates than when the power is off, at the reduced draft.*

2. *The ratio of the extreme impact forces in powered condition to those in not powered condition is 2:1.*

3. ***The extreme thrust on** the centerline shaft recorded was approximately **10 times** the propeller bollard thrust and 1.8 times the maximum nozzle impact force.*

4. *The extreme value of the torque recorded was **12.5 times** the bollard hydrodynamic torque, for the conditions tested.*

5. *The maximum values of the centerline propeller torque and thrust diminish with the increase of model speed.*

6. ***All of the high impact forces on the nozzle were recorded in the astern or near bollard** conditions.*

7. *The maximum impact force on the nozzle was **552%** of the nominal combined bollard thrust of the system.*

8. ***At high model speeds ahead the impact forces were low, if any.***

9. *The **magnitude of impact forces on the nozzle decrease with** the increase of model speed.*

10. *The degree of ice coverage is not correlated strongly with the magnitude of impact forces.*

11. *Lower draft leads to higher impact forces. There is no clear trend between the magnitude of the forces and the draft.*

12. *The extreme nozzle impact forces are effectively located **at r/R = 0.25** above the nozzle axis.*

13. *There is a number of impacts located below the nozzle axis, especially when going astern. This is confirmed by the wax marks on the lower part of nozzle mouth.*

14. *Smaller ice blocks enter the nozzle mouth and create the blockage/milling condition.*

15. *When comparing this test results with the previous tests in ice the following general conclusions can be drawn:*

TABLE 16.2

Comparison of the main test results

| Test conditions | Number of interactions | Blockages |
|---|---|---|
| deep draft<br>large pieces | small | few |
| light draft<br>small pieces | high | many |

## COMPARISON WITH THE FULL SCALE DATA

The twin shaft Polar Stern (draft 10.5 m) has two nozzles of the same diameters as the centerline nozzle of LSSL. Therefore we will compare the nozzle impact loads described in References 14 and 15 fore that ship with the test results. Table 16.3 shows the comparison.

TABLE 16.3

Comparison of the test results with the full scale data

| Vessel | condition | nozzle impact forces |
|---|---|---|
| This series | astern | 516 tonnes |
| This series | ahead | 104 tonnes |
| Polar Stern | astern | 210 tonnes |
|  | ahead | 120 tonnes |
| Nozzle design force |  | 780 tonnes |

Thus we can conclude that the results of the tests were comparable with the full scale data of a similar ship, and that the **forces recorded are within the design capability of the nozzle.**

## *17. RECOMMENDATIONS*

*We recommend the following:*

### *DESIGN/OPERATIONAL RECOMMENDATIONS*

* *The centerline propeller on the triple screw icebreakers is* ***shrouded.***

* *The design of the* ***wing skegs*** *and the* ***direction of the rotation*** *of the wing propellers is changed in the light of the findings of this project.*

* *The ship is operated at the* ***maximum draft****, especially when the astern mode of operations is used frequently.*

* *The* ***stern area of the vessel is redesigned*** *in order to minimize the ice ingestion into the propellers in the astern mode of operations. The redesign may include the hull form and/or addition of the new appendages, like deflectors/sponsons/skegs etc.*

* *The* ***nozzle mouth is redesigned*** *to minimize the effects of the middle part blockage (the most severe blockage condition), by means of the blisters. Those can be installed at the fore and aft end of the nozzle.*

* *The* ***bow of the vessels contains the "step"*** *or another mean of breaking up the envelope of ice, thus permitting it to float up sooner.*

* *The* ***deflectors*** *are structurally capable of sustaining very* ***large ice impact forces in the vertical direction.***

* *The design of the ice deflecting devices* ***reflects the "critical speed" onset of the blocks,*** *beyond which pushing aside of the ice blocks is not effective. Gradual and prolonged pushing action is recommended rather than a quick and forceful.*

* *Using of the* ***waterjets as a mean of deflecting the ice*** *from the propeller area is considered. Those should be applied to the astern operations in particular.*

* *When designing the shrouded propeller, its hydrodynamic characteristics are* ***made tolerant to the large wake fluctuations*** *in the blockage conditions.*

* *The design of the propeller and nozzle system accounts for the forces and vibrations of the system in the blockage onditions.*

# 18. LIST OF REFERENCES

1. Laskow,V., **Propeller Nozzle Application Investigation,** ARAD report to CCG Fleet Systems, March, 1987.

2. Laskow,V., Revill,C.,**Study of Strength Requirements for Nozzles of Ice Transiting Ships**, Transport Development Centre, Montreal, June, 1987, TP6837E.

3. Laskow,V., Spencer,P., Kirby,K., **Robert LeMeur Ice/Propeller Interaction - 1985 Final Report,** Transport Development Centre,
Montreal, April, 1985, TP6176/77/78.

4. Laskow,V., Revill,C., **Engineering Analysis of Ice/Propeller Interaction Data,** Transport Development Centre, Montreal, June,1987.

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88
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c.2

# ICE FLOW AND BLOCKAGE INVESTIGATION
# OF SHROUDED PROPELLERS

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## APPENDICES

by

VLODEK LASKOW
of
**ARCTIC RESEARCH AND DEVELOPMENT LIMITED**
Bragg Creek, Alberta

in cooperation with

**NORDCO LIMITED**
St. John's, Newfoundland

and

**INSTITUTE FOR MARINE DYNAMICS**
St. John's, Newfoundland

PREPARED FOR

**TRANSPORTATION DEVELOPMENT CENTRE**
**POLICY AND COORDINATION GROUP**

TRANSPORT CANADA
Montreal, Quebec

December 27, 1988

416535

## LIST OF APPENDICES

APPENDIX A DETAILED WORK PLAN
APPENDIX B DETAILED TEST PLAN
APPENDIX C DETAILED LITERATURE REVIEW
APPENDIX D FLOAT UP TESTS DETAILS
APPENDIX E WATERJET TESTS DETAILS
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APPENDIX G OVERLOADS TESTS DETAILS
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# APPENDIX A

## DETAILED WORK PLAN

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## ACTIVITY SCHEDULE

### 3.1.DEVELOPMENT AND LISTING OF THE ACTIVITIES (Numbers correspond to those in main report)

3.1.1. Activities schedule

- 3.1.1.1. Development and listing of the activities.
- 1.2. Coordination of the activities with the staff.
- 1.3. Assignment of personnel to each activity.
- 1.4. Time allocation for each activity.
- 1.5. Preparation of the activities schedule.
- 1.6. Identification of the important dates,milestones and provisions for the adjustments by TDC S.A.

3.1.2. Cash flow projection

- 3.1.2.1 Manpower allocation to each activity.
- 2.2. Computations of the labour costs.
- 2.3. Computation of other costs.
- 2.4. Totaling of the costs and drafting of the cash flow projection.

3.1.3. Project management control

- 3.1.3.1. Development of the detailed organizational chart and list of the personnel.
- 3.2. Establishing responsibilities list.
- 3.3. Establishing the communication channels.
- 3.4. Issuing the directives as to the expenditure control by the subcontractors and reporting requirements.

3.1.4. Project documentation procedures

- 3.1.4.1. Establishing standard for the final report.
- .4.2. Establishing standard for the model test data collection format.
- .4.3. Establishing engineering units of measurement and reporting.
- .4.4. Preparing the list of the deliverables and their documentation format.
- .4.5. Assigning the personnel responsible for the delivery of the documentation.

3.1.5. Presentation and approval of this work plan to the TDC S.A

- 3.1.5.1. Issuing of this plan to the project team.
- 5.2. Organization of the kick off meeting in Calgary, including model test manager.
- 5.3. Presentation of the detailed work plan to TDC SA.
- 5.4. Incorporation of the comments and changes to this plan to the satisfaction of the TDC S.A.
- 5.5. Reissue of the approved work plan to project staff.

3.1.6. Writing of CHAPTER 3 of final report

## *3.2. CONDUCTING THE LITERATURE SEARCH.*

*3.2.1. Identifying the sources of literature.*
*3.2.2. Obtaining the relevant literature.*
*3.2.3. Designing the form for the literature review.*
*3.2.4. Reviewing the literature.*
*3.2.5. Summarizing the findings.*
*3.2.6. Returning borrowed literature.*
*3.2.7. Writing CHAPTER 4 of final report.*

## *3.3. DEVELOPING DETAILED TEST PLAN*

*3.3.1. Writing the tentative testing matrix.*
*3.3.2. Identifying the location and the state of the ship model.*
*3.3.3. Listing of the major equipment and parts needed for model testing, including:*

*model*
*propellers*
*nozzle (to be fabricated)*
*nozzle attachment to the hull*
*shafts*
*propulsion motors and controls*
*model attachment to carriage and cabling*
*model ice fabrication equipment*
*model ice material*
*means of supporting the model ice in propeller ice suction tests*

*signal measuring equipment*
*shaft strain gauges (torque and thrust)*
*motor voltage and current measuring devices*
*ice support rods strain gauges*
*nozzle support strain gauges*

*signal conditioning devices*
*signal recording device*
*timing base*

*underwater camera and recording equipment*
*same for the above water equipment*
*lighting,*

*and locations of all of the parts.*

*3.3.4. Identifying how much upgrading of the model (outfitting,painting,sealing,nozzle attachments,etc.) is needed.*
*3.3.5. Selecting procedures for the determining the properties of the model:*

*weight*
*draft*

*3.3.6. Devising procedure for the determination of the properties of ice*
- *density*
- *friction factor*
- *upfloating rate*
- *drag in water*

*3.3.7 Devising the means of attaching the ice blockage pieces to the measuring rod.*
*3.3.8. Listing all of the signals to be collected.*
*3.3.9. Listing the calibration procedures for the signals, calibration constants etc.*
*3.3.10. Listing the data collection and processing apparatus.*
*3.3.11. Establishing the software necessary for the data processing in situ, common time base etc.*
*3.3.12. Finalizing the preliminary test matrix.*
*3.3.13. Establishing the test schedule.*
*3.3.14. Sending it to TDC S.A. for review and approval.*
*3.3.15. Writing the testing specification, explicitly including all of the calibration constants, signal reduction constants for the measuring apparatus etc.*

*3.3.16. Writing CHAPTER 5 of the final report.*

*Detailed test matrix is contained in the APPENDIX C*

## *3.4. CONDUCTING OF THE MODEL TESTS.*

*3.4.1.Calibration of the :*
- *shaft signals*
- *motor signals*
- *nozzle signals*
- *carriage signals*
- *ice support rod gauge signals*

*Calibration procedures will include the comparison of the measured signals with the values calculated by the means of simple engineering calculations.*
*3.4.2. Conducting the basic tests:*
- *ice properties tests*
- *density,*
- *floatup tests*
- *drag tests with and without supporting rod*
- *model/ice friction tests*
- *ice/ice friction tests*

*3.4.3. Conducting the basic model tests (see above)*

*3.4.4. Conducting the first test series (ice flow)*
*See detailed test matrix in the APPENDIX C.*
*3.4.5. Checking of the calibration signals tests.*

*3.4.6. Conducting of the NEW test series (blockages).*
*3.4.7. Rechecking of the calibration signals and repeating of the tests if necessary.*
*3.4.8. Collecting of all the data recorded.*
*3.4.9. Translating all of the signals into the engineering values.*
*3.4.9. Writing CHAPTER 6 of the final report.*

## *3.5. ANALYZING THE MODEL TESTS*

*3.5.1. Preliminary review of the test data and movies.*
*3.5.2. Compiling and analyzing the basic properties data on the ship and ice.*
*3.5.3. Analyzing the propeller suction forces in a graphic form (see below).*
*3.5.4. Producing the required crosscorelations.*
*3.5.5. Determination of the influence of the input parameters on the output parameters:*

*SUCTION TESTS*

| *input* | *output* |
|---|---|
| * *size of ice piece*<br>* *shape of ice piece*<br>* *distance from the prop disk center x,y,z.*<br>* *propulsion power ahead*<br>* *propulsion power astern*<br>* *ship speed ahead*<br>* *ship speed astern*<br>* *ship draft* | *propeller suction force acting on the ice piece.* |

*FLOW TESTS*

| | |
|---|---|
| * *size of ice pieces*<br>* *thickness of the pieces*<br>* *coverage density*<br>* *ship speed ahead*<br>*blockage*<br>*with propeller*<br>* *ship speed astern*<br>* *ship power ahead*<br>* *ship power astern* | *flow pattern along the hull*<br>*speed of approach to prop*<br>*frequency of blockage*<br>*predominant region of*<br>*frequency of interaction*<br>*duration of interaction* |

3.5.6. Developing recommendations as to the modification of the ship's stern region in order to minimize the occurrence and severity of blockages.
3.5.7. Producing he modified model design.
3.5.8. Producing the modified model testing programme.
3.5.9. Writing CHAPTER 7 of the final report.

## 3.6. WRITING OF THE INTERIM REPORT

3.6.1.Describing the original test programme.
3.6.2.Listing of the most important findings.
3.6.3.Detailing proposed model modifications and their rationale.
3.6.4.Evaluating the expected benefits.
3.6.5.Describing the revised test plan.
3.6.6.Producing the 6 copies of the interim report and sending them to TDC S.A. for review and approval.

## 3.7. CONDUCTING THE MODIFIED MODEL TESTS PROGRAMME.

3.7.1.Modifying the model and the nozzle.
3.7.2.Checking the calibration constants.
3.7.3.Retesting the modified model according to the new tests programme.
3.7.4.Collecting,sorting and checking the data.
3.7.5. Analyzing the new data.
3.7.6. Comparing the results of the tests with those from the previous tests.
3.7.7. Drawing the conclusions.
3.7.8. Extrapolating the model test results to the full scale.
3.7.9.Writing CHAPTER 8 of the final report.

## 3.8. WRITING OF THE FINAL REPORT

3.8.1. Reviewing the writing done to date.
3.8.2. Editing it.
3.8.3. Writing CHAPTER 9 of the final report.
3.8.4. Writing CHAPTER 10 of the final report.
3.8.5. Assembling all of the appendices data and checking it against the list of deliverables.
3.8.6. Writing the EXECUTIVE SUMMARY.
3.8.7. Writing the APPENDICES.
3.8.9. Submitting the 6 copies of the final report and one copy of the appendices to the TDC S.A. for his comments and review.
3.8.10 Preparing the verbal presentation of the important findings to the TDC and CCG.
3.8.11. Giving the presentation in Montreal.
3.8.12. Incorporating the suggested improvements and changes to the final report.

3.8.13. *Issuing of the final report.*

### *1.2.ASSIGNMENT OF THE PERSONNEL TO EACH ACTIVITY*

| *ACTIVITY* | *COMPANY* | *PERSONS WORKING* |
|---|---|---|
| *3.1.* | *ARAD* | *V. Laskow* |
| *3.2.* | *ARAD* | *V. Laskow* |
| *3.3.* | *ARAD,NORDCO* | *V. Laskow, M. Koniecki* |
| *3.4.* | *NORDCO,IMD* | *M.Koniecki,G.Hermanski.* |
| *3.5.* | *ARAD,NORDCO* | *V. Laskow, M. Koniecki* |
| *3.6.* | *ARAD* | *V. Laskow* |
| *3.7.* | *NORDCO, IMD* | *M. Koniecki,G.Hermanski* |
| *3.8.* | *ARAD* | *V. Laskow* |

## 1.3 ACTIVITIES SCHEDULE

TIME FRAME, IN WEEKS

```
1987      |OCT                |NOV                     |DEC                |JAN      1988      |FEB
| 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 1  |  2 |  3 |  4 |  5 |

  **   *  3.1   *
          *    *    *    *  3.2
       *    *    *   3.3
                                                       3.4
                          *    *    *    *    *    *    *    *    *    *    *    *    *    *    *
                                                                                        3.5*****
                 3.8
                 *              *                   *         *              *              *         *
A       B       CDE                                                                    F       GH

1988           |MAR                     |APR          |MAY                |JUNE               |JUL
|  6 |  7 |  8 |  9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
 3.5
 ******
           ***3.6
  *    *    *    *   ****** 3.7
           3.8
                 *    *    *    *    *         *         *         *
          I    J KL      M N       O    P    R    S         TU          V

1988                |AUG                |SEPT               |OCT                     |NOV
| 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |


|DEC  1988          |JAN  1989
| 48 | 49 | 50 | 51 | 52 |  1 |  2 |  3 |  4 |  5 |  6 |  7 |  8 |  9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
```

NUMBERS DENOTE THE ACTIVITIES AS IN CHAPTER 3 OF THE MAIN REPORT

## *1.4. LISTING OF IMPORTANT DATES AND MILESTONES*

| *SYMBOL* | *IMPORTANT DATES AND MILESTONES* | | *STATUS* |
|---|---|---|---|
| **A** | ***WRITTEN GO-AHEAD FROM DSS*** | ***15/9/1987*** | * |
| *B* | *Contract signing* | *29/9/1987* | * |
| *C* | *Presentation of the detailed work and test plan* | *6/10/1987* | * |
| *D* | *Approval of the work plan and test plan* | *9/10/1987* | . |
| **E** | *Issuing of the first invoice* | *10/10/1987* | . |
| *F* | *Commencement of model tests* | *18/01/1988* | . |
| *G* | *Completion of the first test series* | *26/01/1988* | . |
| **H** | *Issuing of the second invoice* | *29/01/1987* | . |
| *I* | *Completion of data analysis and new test plan* | *15/2/1988* | . |
| *J* | *Completion of the interim report* | *19/2/1988* | . |
| *K* | *Approval of interim report* | *26/2/1988* | . |
| **L** | *Issuing of the third invoice* | *26/2/1988* | . |
| *M* | *Commencement of the modified model tests* | *14/3/1988* | . |
| *N* | *Completion of the modified test programme* | *19/3/1988* | . |
| *O* | *Completion of the draft final report* | *31/3/1988* | . |
| *P* | *Presentation of draft final report* | *6/4/1988* | . |
| **R** | *Issuing of the fourth invoice* | *18/4/1988* | . |
| *S* | *Completion of the final report revisions* | *29/4/1988* | . |
| *T* | *Issuing of the final report and deliverables* | *13/5/1988* | . |
| **U** | *Issuing of the last,fifth invoice* | *14/5/1988* | . |
| **V** | ***PROJECT TERMINATION*** | *31/5/1988* | . |

### *SUMMARY OF THE ACTIVITIES SCHEDULE*

| *WORK PLAN ITEM* | *ABBREVIATED DESCRIPTION* | *FROM* | *TO* |
|---|---|---|---|
| *3.1.* | *DETAILED WORK PLAN* | *15/9/87* | *23/9/87* |
| *3.2.* | *LITERATURE SEARCH* | *24/9/87* | *16/10/87* |
| *3.3.* | *DETAILED TEST PLAN* | *21/9/87* | *9/10/87* |
| *3.4.* | *MODEL TESTING* | *18/01/87* | *26/02/87* |
| *3.5.* | *ANALYSIS OF RESULTS* | *27/02/88* | *22/02/88* |
| *3.6.* | *INTERIM REPORTING* | *22/02/88* | *26/02/88* |
| *3.7.* | *RETESTING* | *14/3/88* | *18/3/88* |
| *3.8.* | *FINAL REPORTING* | *20/9/87* | *13/5/88* |

| MONTH | MONDAY | | TUESDAY | | WEDNESDAY | | THURSDAY | | FRIDAY | | WK # |
|---|---|---|---|---|---|---|---|---|---|---|---|
| JANUARY | 29 | | 30 | | 31 | | 1 | XXXXXX | 2 | | 1 |
| | 5 | | 6 | | 7 | | 8 | | 9 | | 2 |
| 1987 | 12 | | 13 | | 14 | | 15 | | 16 | | 3 |
| | 19 | | 20 | | 21 | | 22 | | 23 | | 4 |
| | 26 | | 27 | | 28 | | 29 | | 30 | | 5 |
| FEBRUARY | 2 | | 3 | | 4 | | 5 | | 6 | | 6 |
| | 9 | | 10 | | 11 | | 12 | | 13 | | 7 |
| | 16 | | 17 | | 18 | | 19 | | 20 | | 8 |
| | 23 | | 24 | | 25 | | 26 | | 27 | | 9 |
| MARCH | 2 | | 3 | | 4 | | 5 | | 6 | | 10 |
| | 9 | | 10 | | 11 | | 12 | | 13 | | 11 |
| | 16 | | 17 | | 18 | | 19 | | 20 | | 12 |
| | 23 | | 24 | | 25 | | 26 | | 27 | | 13 |
| APRIL | 30 | | 31 | | 1 | | 2 | | 3 | | 14 |
| | 6 | | 7 | | 8 | | 9 | | 10 | | 15 |
| | 13 | | 14 | | 15 | | 16 | | 17 | XXXXXX | 16 |
| | 20 | XXXXXX | 21 | | 22 | | 23 | | 24 | | 17 |
| MAY | 27 | | 28 | | 29 | | 30 | | 1 | | 18 |
| | 4 | | 5 | | 6 | | 7 | | 8 | | 19 |
| | 11 | | 12 | | 13 | | 14 | | 15 | | 20 |
| | 18 | XXXXXX | 19 | | 20 | | 21 | | 22 | | 21 |
| | 25 | | 26 | | 27 | | 28 | | 29 | | 22 |
| JUNE | 1 | | 2 | | 3 | | 4 | | 5 | | 23 |
| | 8 | | 9 | | 10 | | 11 | | 12 | | 24 |
| | 15 | | 16 | | 17 | | 18 | | 19 | | 25 |
| | 22 | | 23 | | 24 | | 25 | | 26 | | 26 |
| JULY | 29 | | 30 | | 1 | XXXXXX | 2 | | 3 | | 27 |
| | 6 | | 7 | | 8 | | 9 | | 10 | | 28 |
| | 13 | | 14 | | 15 | | 16 | | 17 | | 29 |
| | 20 | | 21 | | 22 | | 23 | | 24 | | 30 |
| | 27 | | 28 | | 29 | | 30 | | 31 | | 31 |
| AUGUST | 3 | | 4 | | 5 | | 6 | | 7 | | 32 |
| | 10 | | 11 | | 12 | | 13 | | 14 | | 33 |
| | 17 | | 18 | | 19 | | 20 | | 21 | | 34 |
| | 24 | | 25 | | 26 | | 27 | | 28 | | 35 |
| SEPTMBER | 31 | | 1 | | 2 | | 3 | | 4 | | 36 |
| | 7 | XXXXXX | 8 | | 9 | | 10 | | 11 | | 37 |
| | 14 | | 15 | A | 16 | | 17 | | 18 | | 38 |
| | 21 | | 22 | | 23 | | 24 | | 25 | | 39 |
| OCTOBER | 28 | | 29 | B | 30 | | 1 | | 2 | | 40 |
| | 5 | | 6 | C | 7 | | 8 | | 9 | D,E | 41 |
| | 12 | XXXXXX | 13 | | 14 | | 15 | | 16 | | 42 |
| | 19 | | 20 | | 21 | | 22 | | 23 | | 43 |
| | 26 | | 27 | | 28 | | 29 | | 30 | | 44 |
| NOVEMBER | 2 | | 3 | | 4 | | 5 | | 6 | | 45 |
| | 9 | | 10 | | 11 | XXXXXX | 12 | | 13 | | 46 |
| | 16 | | 17 | | 18 | | 19 | | 20 | | 47 |
| | 23 | | 24 | | 25 | | 26 | | 27 | | 48 |
| DECEMBER | 30 | | 1 | | 2 | | 3 | | 4 | | 49 |
| | 7 | | 8 | | 9 | | 10 | | 11 | | 50 |
| | 14 | | 15 | | 16 | | 17 | | 18 | | 51 |
| 1987 | 21 | | 22 | | 23 | | 24 | | 25 | XXXXXX | 52 |
| | 28 | | 29 | | 30 | | 31 | | 1 | XXXXXX | 53 |

| MONTH | MONDAY | | TUESDAY | | WEDNESDAY | | THURSDAY | | FRIDAY | | WK # |
|---|---|---|---|---|---|---|---|---|---|---|---|
| JANUARY | 28 | | 29 | | 30 | | 31 | | 1 | XXXXXX | 53 |
| | 4 | | 5 | | 6 | | 7 | | 8 | | 1 |
| 1988 | 11 | | 12 | | 13 | | 14 | | 15 | | 2 |
| | 18 | F | 19 | | 20 | | 21 | | 22 | | 3 |
| | 25 | | 26 | G | 27 | | 28 | | 29 | H | 4 |
| FEBRUARY | 1 | | 2 | | 3 | | 4 | | 5 | | 5 |
| | 8 | | 9 | | 10 | | 11 | | 12 | | 6 |
| | 15 | I | 16 | | 17 | | 18 | | 19 | J | 7 |
| | 22 | | 23 | | 24 | | 25 | | 26 | K L | 8 |
| MARCH | 29 | | 1 | | 2 | | 3 | | 4 | | 9 |
| | 7 | | 8 | | 9 | | 10 | | 11 | | 10 |
| | 14 | M | 15 | | 16 | | 17 | | 18 | N | 11 |
| | 21 | | 22 | | 23 | | 24 | | 25 | | 12 |
| APRIL | 28 | | 29 | | 30 | | 31 | O | 1 | XXXXXX | 13 |
| | 4 | XXXXXX | 5 | | 6 | P | 7 | | 8 | | 14 |
| | 11 | | 12 | | 13 | | 14 | | 15 | | 15 |
| | 18 | R | 19 | | 20 | | 21 | | 22 | | 16 |
| MAY | 25 | | 26 | | 27 | | 28 | | 29 | S | 17 |
| | 2 | | 3 | | 4 | | 5 | | 6 | | 18 |
| | 9 | | 10 | | 11 | | 12 | | 13 | T | 19 |
| | 16 | | 17 | | 18 | | 19 | | 20 | | 20 |
| | 23 | XXXXXX | 24 | | 25 | | 26 | | 27 | | 21 |
| JUNE | 30 | | 31 | V | 1 | | 2 | | 3 | | 22 |
| | 6 | | 7 | | 8 | | 9 | | 10 | | 23 |
| | 13 | | 14 | | 15 | | 16 | | 17 | | 24 |
| | 20 | | 21 | | 22 | | 23 | | 24 | | 25 |
| JULY | 27 | | 28 | | 29 | | 30 | | 1 | XXXXXX | 26 |
| | 4 | | 5 | | 6 | | 7 | | 8 | | 27 |
| | 11 | | 12 | | 13 | | 14 | | 15 | | 28 |
| | 18 | | 19 | | 20 | | 21 | | 22 | | 39 |
| | 25 | | 26 | | 27 | | 28 | | 29 | | 30 |
| AUGUST | 1 | | 2 | | 3 | | 4 | | 5 | | 31 |
| | 8 | | 9 | | 10 | | 11 | | 12 | | 32 |
| | 15 | | 16 | | 17 | | 18 | | 19 | | 33 |
| | 22 | | 23 | | 24 | | 25 | | 26 | | 34 |
| SEPTMBER | 29 | | 30 | | 31 | | 1 | | 2 | | 35 |
| | 5 | XXXXXX | 6 | | 7 | | 8 | | 9 | | 36 |
| | 12 | | 13 | | 14 | | 15 | | 16 | | 37 |
| | 19 | | 20 | | 21 | | 22 | | 23 | | 38 |
| OCTOBER | 26 | | 27 | | 28 | | 29 | | 30 | | 49 |
| | 3 | | 4 | | 5 | | 6 | | 7 | | 40 |
| | 10 | XXXXXX | 11 | | 12 | | 13 | | 14 | | 41 |
| | 17 | | 18 | | 19 | | 20 | | 21 | | 42 |
| | 24 | | 25 | | 26 | | 27 | | 28 | | 43 |
| NOVEMBER | 31 | | 1 | | 2 | | 3 | | 4 | | 44 |
| | 7 | | 8 | | 9 | | 10 | | 11 | XXXXXX | 45 |
| | 14 | | 15 | | 16 | | 17 | | 18 | | 46 |
| | 21 | | 22 | | 23 | | 24 | | 25 | | 47 |
| DECEMBER | 28 | | 29 | | 30 | | 1 | | 2 | | 48 |
| | 5 | | 6 | | 7 | | 8 | | 9 | | 59 |
| | 12 | | 13 | | 14 | | 15 | | 16 | | 50 |
| 1988 | 19 | | 20 | | 21 | | 22 | | 23 | | 51 |
| | 26 | XXXXXX | 27 | XXXXXX | 28 | | 29 | | 30 | | 52 |

## 1.5. MANPOWER ALLOCATION TO EACH ACTIVITY

| ACTIVITY | MANPOWER, IN MANDAYS, FOR EACH LABOR CATEGORY | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WORK PLAN ITEM | ARAD | NORDCO | | | | | | | | | | | | IMD | | | |
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | R |
| 3.1. | 5 | | | | | | | | | | | | | | | | |
| 3.2. | 5 | | 2 | 2 | | | | | | | | | | | | | |
| 3.3. | 5 | 4 | 2 | 2 | | | | | | | | | | | | | |
| 3.4. | 20 | 3 | 10 | 20 | 30 | 15 | | | | | | | | 2 | 5 | 7 | |
| 3.5. | 20 | 5 | 9 | 7 | | | | | | | | | | | | | |
| 3.6. | 5 | | | | | | | | | | | | | | | | |
| 3.7. | 10 | 7 | 10 | 13 | 20 | 15 | | | | | | | | 1 | 2 | 3 | |
| 3.8. | 20 | | 5 | 5 | | | | | | | | | | | | | |
| SUB TOTAL | 90 | 19 | 38 | 49 | 50 | 30 | | | | | | | | 3 | 7 | 10 | |
| TOTAL | 90 | | | | | | | | | | | | 186 | | | | 20 |

GRAND TOTAL 296 MANDAYS

Manpower category and the chargeout rates are as follows:

| | |
|---|---|
| A PRINCIPAL, PROJECT MANAGER AND TECHNICAL SPECIALIST | $630/DAY |
| B SENIOR SUPERVISING ENGINEER/SCIENTIST | $398/DAY |
| C SENIOR ENGINEER/SCIENTIST | $289/DAY |
| D ENGINEER/SCIENTIST | $247/DAY |
| E SENIOR TECHNICIAN/PROGRAMMER | $246/DAY |
| F MACHINE SHOP TECHNICIAN | $246/DAY |
| N RESEARCH OFFICER | $450/DAY |
| O TECHNICAL OFFICER | $375/DAY |
| P TANK OPERATOR | $500/DAY |

### 1.6.COMPUTATIONS OF THE LABOUR COSTS

Labour costs are computed using the manpower allocation table:

| WORK PLAN ITEM | TOTAL MANPOWER,MANDAYS LETTERS DENOTE LABOUR CATEGORY, NUMBERS DENOTE MDAYS | TOTAL LABOUR COSTS |
|---|---|---|
| 3.1 | A*5 | $3,150.00 |
| 3.2 | A*5 + C*2 + D*2 | $4,222.00 |
| 3.3 | A*5 +B*4 + C*2 + D*2 | $5,814.00 |
| 3.4. | A*20 +B*3 + C*10+ D*20 +E*30+F*15+P*7+N*2+0*5 | $38,969.00 |
| 3.5. | A*20 +B*5 + C*9 + D*7 | $18,920.00 |
| 3.6. | A*5 | $3,150.00 |
| 3.7. | A*10 +B*7 + C*10+ D*13 +E*20+F*15+P*3+N*1+O*2 | $26,497.00 |
| 3.8. | A*20 + C*5 + D*5 | $15,280.00 |
| | A=90 B=19 C=38 D=49 E=50 F=30 P=10 N=3 O=7 | $116,002.00 |

DISTRIBUTION OF LABOR COSTS

| | | |
|---|---|---|
| ARAD | $56,700 | |
| NORDCO | $50,327 | (EXCLUDING PROFIT) |
| IMD | $8,975 | |
| **TOTAL LABOUR** | **$116,002** | |

OTHER COSTS

| DESCRIPTION | COST | ALLOCATED TO TASK | STARTING DATE | COMPANY |
|---|---|---|---|---|
| COMMUNICATIONS | $800 | 3.1. | 15/9/1987 | ARAD |
| TRAVEL | $5,655 | 3.4. | 17/01/1988 | ARAD |
| PRINTING | $5,500 | 3.8. | 31/3/1987 | ARAD |
| | **$11,955** | | | |
| MATERIALS | $6,500 | 3.4. | 19/10/1987 | NORDCO |
| COMMUNICATIONS | $200 | 3.1. | 15/9/1987 | NORDCO |
| TRAVEL | $3,000 | 3.1. | 15/9/1987 | NORDCO |
| PRINTING | $2,500 | 3.8. | 31/3/1988 | NORDCO |
| PROFIT | $5,960 | 3.8. | 31/3/1988 | NORDCO |
| ADDITIONS TO MDL | $21,000 | 3.4 | 19/10/1987 | NORDCO |
| | **$39,160** | | | |
| MODEL BASIN | **$22,200** | 3.4. | 7/12/1987 | IMD |
| **TOTAL, OTHER** | **$73,315** | | | |

| TOTAL PROJECT COSTS | LABOUR | | OTHER | | TOTAL |
|---|---|---|---|---|---|
| ARAD............................. | $56,700 | + | $11,955 | = | $68,655 |
| NORDCO........................... | $50,327 | + | $39,160 | = | $89,487 |
| IMD.............................. | $ 8,975 | + | $22,200 | = | $31,175 |
| **ALL COMPANIES......................** | **$116,002** | **+** | **$73,315** | **=** | **189,317** |

## 1.7 CASH FLOW CALCULATIONS

### CASH FLOW DISTRIBUTION

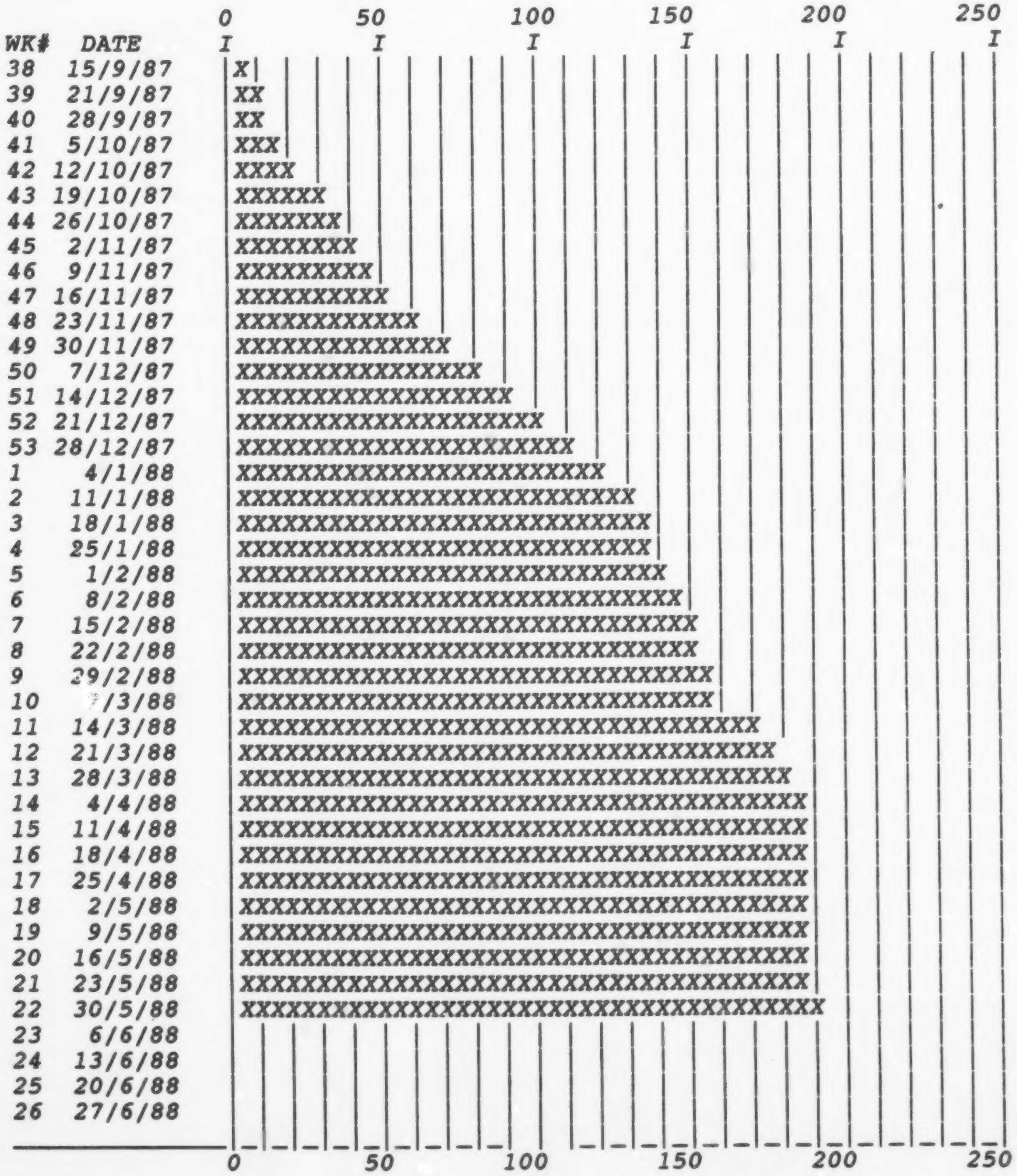
| ACTIVITY ITEM | DURATION WKS | TOTAL COSTS,$ | DISTRIBUTED COSTS $/WK | STARTING DATE | |
|---|---|---|---|---|---|
| 3.1 | 2 | 7,150 | 3,575 | 15/9/87 | |
| 3.2 | 3 | 4,222 | 1,407 | 24/9/87 | |
| 3.3 | 5 | 5,814 | 1,163 | 21/9/87 | |
| 3.4 | 15 | 94,324 | 6,288 | 19/10/87 | (INCL PREPS) |
| 3.5 | 4 | 18,920 | 4,730 | 27/1/88 | |
| 3.6 | 1 | 3,150 | 3,150 | 22/2/88 | |
| 3.7 | 2 | 26,497 | 13,250 | 14/3/88 | |
| 3.8 | 30 | 29,240 | 975 | 21/9/87 | (INCL STARTUP) |
| | | $ 189,317 | | | |

| | | | COSTS | | | | | |
|---|---|---|---|---|---|---|---|---|
| WK# | DATE | ACTIVITY | DISTRIBUTED COSTS | | | | | ACCUMULATED COSTS |
| 38 | 15/9/87 | 3.1 | | 3575 | | | | 3,575 |
| 39 | 21/9/87 | 3.2,3.3,3.8 | | 3575 | 1407 | 1163 | 975 | 10,695 |
| 40 | 28/9/87 | | | | 1407 | 1163 | 975 | 14,240 |
| 41 | 5/10/87 | | | | 1407 | 1163 | 975 | 17,785 |
| 42 | 12/10/87 | | | | | 1163 | 975 | 19,923 |
| 43 | 19/10/87 | 3.4 | | | 6288 | 1163 | 975 | 28,349 |
| 44 | 26/10/87 | | | | 6288 | | 975 | 35,612 |
| 45 | 2/11/87 | | | | 6288 | | 975 | 42,875 |
| 46 | 9/11/87 | | | | 6288 | | 975 | 50,138 |
| 47 | 16/11/87 | | | | 6288 | | 975 | 57,401 |
| 48 | 23/11/87 | | | | 6288 | | 975 | 64,664 |
| 49 | 30/11/87 | | | | 6288 | | 975 | 71,927 |
| 50 | 7/12/87 | | | | 6288 | | 975 | 79,190 |
| 51 | 14/12/87 | | | | 6288 | | 975 | 86,453 |
| 52 | 21/12/87 | | | | 6288 | | 975 | 93,716 |
| 53 | 28/12/87 | | | | 6288 | | 975 | 100,979 |
| 1 | 4/1/88 | | | | 6288 | | 975 | 108,242 |
| 2 | 11/1/88 | | | | 6288 | | 975 | 115,505 |
| 3 | 18/1/88 | | | | 6288 | | 975 | 122,768 |
| 4 | 25/1/88 | 3.5 | 4730 | | 6288 | | 975 | 134,761 |
| 5 | 1/2/88 | | 4730 | | | | 975 | 140,466 |
| 6 | 8/2/88 | | 4730 | | | | 975 | 146,171 |
| 7 | 15/2/88 | | 4730 | | | | 975 | 151,876 |
| 8 | 22/2/88 | | | 3.6 | 3150 | | 975 | 155,476 |
| 9 | 29/2/88 | | | | | | 975 | 156,451 |
| 10 | 7/3/88 | | | | | | 975 | 157,426 |
| 11 | 14/3/88 | | | 3.7 | 13250 | | 975 | 171,651 |
| 12 | 21/3/88 | | | | 13250 | | 975 | 185,876 |
| 13 | 28/3/88 | | | | | | | 185,876 |
| 14 | 4/4/88 | | | | | | 975 | 186,851 |
| 15 | 11/4/88 | | | | | | | 186,851 |
| 16 | 18/4/88 | | | | | | | 186,851 |
| 17 | 25/4/88 | | | | | | 968 | 187,819 |
| 18 | 2/5/88 | | | | | | | |
| 19 | 9/5/88 | | | | | | 968 | 188,783 |
| 20 | 16/5/88 | | | | | | | |
| 21 | 23/5/88 | | | | | | 530 | 189,317 |
| 22 | 30/5/88 | | | | | project ends | | |
| 23 | 6/6/88 | | | | | | | |
| 24 | 13/6/88 | | | | | | | |
| 25 | 20/6/88 | | | | | | | |
| 26 | 27/6/88 | | | | | | | |

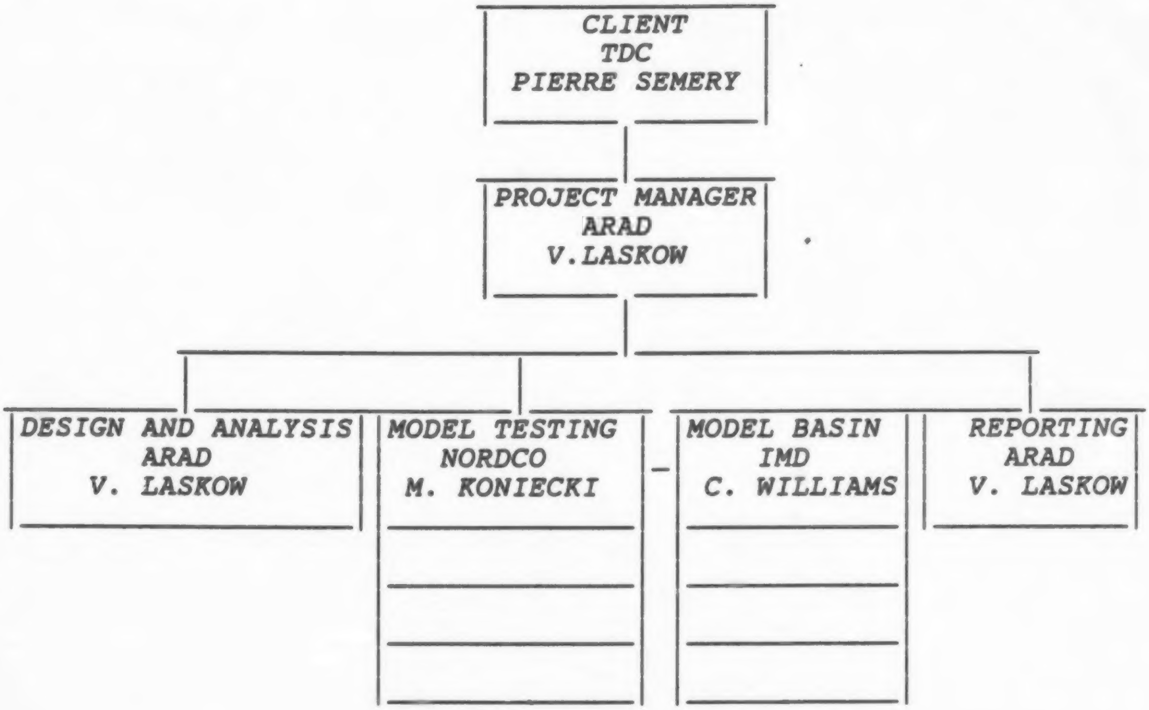
TOTAL PROJECT $189,317

COSTS, IN THOUSANDS,

X DENOTES CURRENT COSTS,   O DENOTES ACCUMULATED COSTS



PROJECT MANAGEMENT CONTROL
## 1.9.ORGANIZATION CHART



*NOTE: For convenience sake, IMD will report directly to NORDCO on the matters of model testing.*

LIST OF PERSONNEL

| Name | Company |
|---|---|
| V. Laskow | ARAD |
| M. Koniecki | NORDCO |
| G.Hermanski | NORDCO |
| C.Williams | IMD |

THEE BINDING AGREEMENTS BETWEEN ARAD AND NORDCO AND NORDCO AND IMD ARE ATTACHED AT THE END OF THIS APPENDIX.

## LIST OF RESPONSIBILITIES

| WORK PLAN ITEM | DESCRIPTION | RESPONSIBLE COMPANY | WORKING ON THE TASK |
|---|---|---|---|
| 3.1. | DETAILED WORK PLAN | ARAD | ARAD, NORDCO |
| 3.2. | LITERATURE SEARCH | ARAD | ARAD, NORDCO |
| 3.3. | TEST PLAN | ARAD | ARAD, NORDCO, IMD |
| 3.4. | MODEL TESTS | NORDCO | NORDCO,IMD |
| 3.5. | ANALYSIS | ARAD | ARAD, NORDCO |
| 3.6. | INTERIM REPORT | ARAD | ARAD |
| 3.7. | RETESTING | NORDCO | NORDCO, IMD |
| 3.8. | REPORTING | ARAD | ARAD, NORDCO |

ARCTIC RESEARCH AND DEVELOPMENT LTD (ARAD) WILL BE RESPONSIBLE FOR THE SUCCESS OF THE PROJECT.

INSTITUTE FOR MARINE DYNAMICS(IMD) WILL BE RESPONSIBLE FOR THE PROVISION AND INSTRUMENTATION OF THE MODEL, FABRICATION AND INSTALLATION OF THE NOZZLE, OPERATION OF THE MODEL BASIN AND ASSOCIATED RECORDING EQUIPMENT.

NEWFOUNDLAND OCEANS RESEARCH AND DEVELOPMENT CORPORATION (NORDCO) WILL BE RESPONSIBLE FOR THE FABRICATION TO RECOGNIZED SCALING LAWS AND INSTRUMENTATION OF SIMULATED ICE PIECES, OPERATION OF THE ASSOCIATED RECORDING EQUIPMENT, INSTRUMENTATION OF THE NOZZLE AND DAY TO DAY CONDUCTING OF THE TESTS.

## COMMUNICATION CHANNELS

V.LASKOW will be the only contact with the CLIENT, Mr Pierre Semery, except when absent. In such a case, Mr Koniecki will be the contact person.

All communications will be directed to Mr Laskow, PROJECT MANAGER.

COMPLETE LIST OF ADDRESSES, PHONE AND FAX NUMBERS IS GIVEN ON THE FOLLOWING PAGE.

# COMMUNICATION SHEET

**DSS CONTRACT SERIAL NUMBER:......................12SD.T8200-7-7523**
PROJECT TITLE:....**ICE FLOW AND BLOCKAGE INVESTIGATION OF SHROUDED PROPELLERS.**

PROJECT OFFICER (TDC):..................MR PIERRE SEMERY,P.ENG,SDO
PHONE.........................................1-514-283-0030
FAX...........................................1-514-283-7158
ADDRESS.............CENTRE DE DEVELOPMENT DES TRANSPORTS,COMPLEXE GUY-FAVREAU, 200 OUEST, BOUL.DORCHESTER.SUITE 601,TOUR OUEST,MONTREAL QUE H2Z 1X4

PROJECT MANAGER (ARAD)..................VLODEK LASKOW,P.ENG (QUE)
PHONE........................................ 1-403-949-2134
FAX.......................................... 1-403-949-2134
ADDRESS.......ARCTIC RESEARCH AND DEVELOPMENT LTD,PO BOX 85 BRAGG CREEK, ALBERTA, TOL OKO

SUBCONTRACTOR MANAGER (NORDCO).................. MARIUSZ KONIECKI
PHONE.........................................1-709-772-2473
FAX...........................................1-709-772-2462
ADDRESS......................NORDCO LTD,PO BOX 8833, ST. JOHN'S, NEWFOUNDLAND, A1B 3T2

PROCUREMENT OFFICER (DSS)..................RICHARD SIMPSON,SSPO
FAX...........................................1-514-283-5708
PHONE.........................................1-514-283-6625
ADDRESS....SUPPLY AND SERVICES CANADA,800 GULF ROAD, NUN'S ISLAND QUEBEC, H3E 1G9

MODEL BASIN MANAGER (IMD)......................DR. CHRIS WILLIAMS
FAX...........................................1-709-772-2462
PHONE.........................................1-709-772-4221
ADDRESS.......... NATIONAL RESEARCH COUNCIL, INSTITUTE FOR MARINE DYNAMICS, PO BOX 12093,STATION "A", ST. JOHN'S, NEWFOUNDLAND,A1B 3T5

## EXPENDITURE CONTROLS

*EACH COMPANY WILL REPORT ITS EXPENDITURES ACCRUED FOR EACH TASK TO THE PROJECT MANAGER. UPON COMPLETION OF EACH TASK, A DETAILED COST REPORT SUMMARY WILL BE PRESENTED TO THE PROJECT MANAGER. THE AMOUNTS ALLOCATED FOR EACH TASK ARE NOT TO BE EXCEEDED.*

*Each company will keep a proper accounting system for the purpose of project cost control. Each expenditure item will be FULLY DOCUMENTED, as required by DSS standards.*
*Each company will account for the manpower effort and keep ACCURATE TIME SHEETS of the personnel working on the project.*

*SOME ADJUSTMENTS OF THE EXPENDITURES BETWEEN THE TASKS ARE ALLOWED, after being approved by the PROJECT MANAGER AND TDC S.A.*

*SUBCONTRACTORS WILL BE REIMBURSED FOR THEIR COSTS,UP TO THE CONTRACTED AMOUNTS, AFTER THE MONIES ARE RECEIVED FROM DSS, EXCEPT FOR THE AMOUNT BEING WITHHELD BY DSS.*

## PROJECT DOCUMENTATION PROCEDURES

*FINAL REPORT will be written to the TDC report standard:*

*TDC PUBLICATION STANDARDS FOR CONTRACTORS.*

*All subcontractors are to use this standard for reporting their work. Requirements set out by DSS and TDC in APPENDIX A to the CONTRACT REGARDING PROJECT DOCUMENTATION FORMATS AND PROCEDURES will be adhered to by all participating parties.*

*SUBCONTRACTORS REPORTS will form an integral part of the MAIN REPORT and APPENDICES.*

*Subcontractors will write their PRELIMINARY REPORTS immediately after their tasks are completed. These reports are to be submitted to the PROJECT MANAGER for his review and comments. The comments are to be incorporated in the reports shortly after their receipt, AND WILL THEN BECOME FINAL REPORTS.*
*Two copies of the reports are to be submitted to the PROJECT MANAGER for the review, during the project. The number of copies of the subcontractor's FINAL REPORTS will be as set in APPENDIX A to the CONTRACT plus 2.*

*REPORTS will be written to high professional standards, will be clear, concise and complete. All changes, amendments and corrections to the reports will be done at no extra cost to the contractor or the crown.*

*The following is the list of the reports:*

| report | task | author | format |
|---|---|---|---|
| INTERIM REPORT | 3.6. | ARAD | self contained |
| FINAL REPORT | 3.8. | ARAD | self contained |
| MODEL TESTS | 3.4. | NORDCO | appendix to FR |
| RETESTING | 3.7. | NORDCO | appendix to FR |

MODEL TESTS DATA DOCUMENTATION FORMATS

Electronic data:
1 Mag tape containing all of raw data
2. $5^1/_4$ floppy diskettes for individual tests and/or events.
3. Paper copy of all relevant signals/tests/events.

Visual data:
1. Video tapes, beta format
2. Still photographs, 4x6

Other:
Test logs and field notes fully legible and reproducible
Calibration charts and documentation hard copy.
SYSTEM OF UNITS AND MEASUREMENTS..........SI.

LIST OF DELIVERABLES:

| ITEM | DESCRIPTION | NUMBER OF COPIES | FORMAT | RESPONSIBILITY |
|---|---|---|---|---|
| 0. | INTERIM REPORT | 6 | HARD COPY, BOUND | ARAD, VL |
| 1. | FINAL REPORT | 30 | HARD COPY,BOUND | ARAD, VL |
| 2. | APPENDICES A,B,C | 1 | HARD COPY, BOUND | ARAD, VL |
| 3. | APPENDICES D,E,F | 1 | HARD COPY, BOUND | NORDCO, MK |
| 4. | EXEC. SUMMARY | 30 | PART OF FINAL RPT | ARAD, VL |
| 5. | TEST DOCUMENTATION | 1 | DISKETTES,TAPES, PHOTOS, PACKAGED. | NORDCO, MK |

END OF APPENDIX A

# APPENDIX B

## DETAILED TEST PLAN

*TABLE OF CONTENTS*

*1. RATIONALE..................................5*
*2. TEST PROGRAMME.............................7*
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*4. CALIBRATIONS..............................15*
*5. EQUIPMENT.................................15*
*6. DATA TO BE COLLECTED......................15*
*7. FORMAT OF THE RESULTS.....................16*

## *1. RATIONALE*

*The REASONS for launching this test series are as follows:*

- *Blockage of shrouded propellers is a menace to icebreaking ship operators.*
- *Elimination of blockage would improve icebreaking efficiency and safety of arctic marine transportation systems.*
- *Physical phenomena underlying the blockage mechanism are not known (suction forces, flow patterns)*
- *Only after gaining a good understanding of the blockage physics,can blockage prevention measures can be successfully adopted.*
- *Full scale blockage trials would be prohibitively expensive and impractical.*
- *Theoretical modeling of the blockage phenomenon would be very questionable, as the mechanics of blockage is not known and no data exists upon which a theory could be based.*
- *Thus only the model tests can provide any information needed for the understanding and consequent control of blockages.*
- *By choosing a specific ship which will be outfitted with the nozzle in the near future, the blockage countermeasures developed in the course of this project, can be immediately implemented.*
- *In model tests of this type, the most important parameters are the geometry of the ice pieces, their density (which governs the buoyancy forces), friction factor against the hull, their viscous drag and the pressure field generated by the propellers.*
- *As ice strength and other material properties of ice are not important, (blockage involves solid pieces of ice) the model paraffin ice can be used, provided it has the proper mass, geometrical and frictional characteristics.*
- *Two aspects of ship/ice and propeller/ice interaction are essential for understanding of the blockage phenomena:*
  *flow of ice pieces under the hull, and*
  *suction of ice pieces into the nozzle.*
- *Thus two types of the systematic test series are undertaken:*
  *flow tests, and*
  *suction tests.*

  ***ICE Flow tests*** *are designed to systematically vary the physical parameters governing the flow of ice pieces under the hull (ice size, coverage, ships speed, power and draft). Establishing the influence of these parameters on the amount and severity of blockage will help the operators in controlling the frequency of blockages by changing the operating parameters.*

  ***ICE Suction tests*** *are designed to determine the influence of the propeller pressure field on the flow of ice pieces* in the vicinity of the nozzle and the severity of blockages.

* Once the results of the tests are known and understood, the blockage preventive measures can be devised, implemented and verified by means of the revised design model tests.
* The effectiveness of the blockage countermeasures can then be assessed. If positive, these countermeasures will be recommended for full scale applications on icebreaking ships.

As the applicability of the model test results to the full scale is important, Froude's Scaling Laws will be adopted. These laws permit,the correct extrapolation of propeller suction forces, buoyancy forces and friction forces. Viscous drag forces, while they cannot be scaled correctly using Froude's Scaling Laws, can nevertheless be correctly calculated and extrapolated to the full scale.

## 2. TEST PROGRAMME

### 2.0. MODEL AND BASIC SETTINGS

*The model used for the purpose of these tests will be 1:15 SCALE CCGS LOUIS S. ST LAURENT, currently available at IMD.*
*The model will be outfitted with all of the appendages, three propellers and a nozzle, especially fabricated for these tests. The stern lines of the model will have to be refined.*

*THE FULL POWER will be set at.............21,000.DHP, equally distributed on three shafts.*
*The maximum DRAFT will be.....................9.m,even keel.*

### 2.1. ICE PROPERTIES CALIBRATION TESTS

*2.1.1 Buoyancy of ice tests*
*These will determine if the upward force acting on a stationary paraffin ice piece is equal to that of the real ice of the same geometry.*

*2.1.2 Friction ice/ice tests*
*These will determine if the frictional forces acting between the submerged paraffin ice pieces are equal to those of real ice.*

*2.1.3 Friction ice/ hull tests*
*Ditto for the forces between ice and the hull.*

*2.1.4 Floatup tests (all sizes, 3 drafts, face up/edge up).*
*These tests will determine the time needed for a particular ice piece to float up from a given depth to the surface.*

*2.1.5 Drag tests edge-wise and face-wise*
*These tests will determine the water drag forces acting on the ice blocks as a function of their geometry and the speed of motion.*

*At the completion of these tests, the*
*static, (buoyancy tests)*
*steady state motion, (drag & friction tests)*
*transient state motion (float up tests)*
*properties of ice pieces will be known and understood to the degree permitting the implementation and interpretation of the main test series.*

*The above tests will be repeated as many times as necessary to obtain consistent data sets.*

## 2.2. SHIP PROPERTIES CALIBRATION TESTS.

### 2.2.1. Self propulsion tests

2.2.1.1. Thrust and torque on the centerline shaft as a function of the motor power, RPM, speed of advance of the free running model and the direction of rotation of the centerline shaft.

2.2.1.2. Forces acting on the nozzle as a function of the above parameters. The power will be distributed equally on all three shafts during these tests.

2.2.1.3. Overload tests, including the bollard tests ahead and astern. The test matrix will be:

| SHIP SPEED, kn f.s. | | SHIP POWER, % of full |
|---|---|---|
| AHEAD | ASTERN | equally distributed on 3 shafts |
| 0 | | 100, 75, 50, 25, 1 |
| 5 | | 100, 75, 50 |
| 10 | | 100, 75 |
| 15 | | 100 |
| | 0 | 100, 75, 50, 25, 1 |
| | 2 | 100, 75, 50 |
| | 4 | 100, 75 |
| | 6 | 100 |

During these tests, only shaft thrust,torque and the nozzle force will be determined, so they can then be compared with those occurring during the blockages.

### 2.2.1.2. Hull tests.

Standard setup tests giving the proper weight of the model at these drafts:

% of maximum
100
80

## 2.3. ICE FLOW TESTS.

### 2.3.1. ICE PROPERTIES AND GEOMETRY.

*The blockage can occur only when ice spacial dimensions are equal to or greater than those of the nozzle. The diameter of the nozzle is approx 6m ,and its mouth's half section area is: 14m^2.*

*The following ice properties matrix is envisaged for the purpose of these tests:*

| # | ice thickness m | surface area m^2 | shape | surface level | coverage ridge |
|---|---|---|---|---|---|
| 1 | 1.0 (basic test) | 20 | rhomb | * | * |
| 2 | | 10 | rhomb | * | * |
| 3 | 2.0 (optional) | 20 | rhomb | * | * |

*The level ice coverage with the prebroken ice pieces will be approximately 100%, while the depth of the ridge will be 4 times the level ice thickness and with an equal horizontal extension. These are thought to be the extreme conditions leading to frequent blockages.*

*The ship variables will be:*

| ice condition | power % of max | speed ahead | speed astern | draft % of max |
|---|---|---|---|---|
| 1 | 100 | 0 | - | 100,80 |
| | 100 | - | 0 | 100,80 |
| (basic test) | 100 | 3 | - | 100,80 |
| | 100 | - | 1.5 | 100,80 |
| 2 | 100 | 0 | - | 100 |
| | 100 | - | 0 | 100 |
| 3 | 100 | 0 | - | 100 |
| | 100 | - | 0 | 100 |
| | 100 | 3 | - | 100 |
| | 100 | - | 1.5 | 100 |

*The tests will be conducted the following manner:*

*The ship will be towed thru the level ice field at a given speed and power setting. At least three passages thru each ice condition will be required in order to assure a sufficient degree of repeatability.*

After the level ice tests are completed, the pieces will be pushed together, forming a simulated ridge/rafted ice field, and the model will be pulled thru it at a predetermined speed. THIS IS AN OPTIONAL TEST, depending on the availability of the tank.

The influence of the different parameters on the ice flow and the amount of blockage will be assessed by changing these parameters from the BASIC TEST,which is:

### BASIC TEST

| | | |
|---|---|---|
| I | ice thickness............ | 1m |
| C | ice condition............. | 100% coverage, level. |
| E | block size................ | 20 m^2 |
| | block shape............... | rhomb. |
| S | ship speed.......... | ahead, 3 knots |
| H | ship power................. | 100% |
| I | ship draft................. | 100% |
| P | | |

### 2.3.2. INFLUENCE OF DRAFT TESTS

These tests will be conducted in one ice thickness only, that is, the limiting thickness of CCGS Louis St. Laurent, which is 1m.

Three drafts and three runs for each draft will be executed at the same power level, ahead and astern, in level ice and in ridges.

Basic test draft condition will be varied as follows:

100%, 80%

of the maximum draft.
In addition, astern speed of 1.5 knots will be repeated at these drafts.

If time will allow, the influence of the trim will also be assessed, having the ship rerun the basic test at 2 meters trim by the stern. THIS IS AN OPTIONAL TEST.

### 2.3.4. INFLUENCE OF COVERAGE tests

One set of level ice conditions (# 1 or the one giving the most blockage events) will be rerun in different level ice coverages:

Basic test (given above) 100% coverage
90% coverage
60% coverage

### 2.3.5. INFLUENCE OF SHIP SPEED

A basic test will be rerun at different ship speeds, ie:

| | |
|---|---|
| ahead | 0.1 knot (near bollard) |
| ahead | 5 knots |
| astern | 0.1 knot (near bollard) |
| astern | 1 knot |
| astern | 2 knots |

### 2.3.6. INFLUENCE OF POWER LEVEL.

Basic test power level will be varied as follows:

| | ship speed | power level |
|---|---|---|
| ahead | near bollard | 100 |
| | | 75 |
| | | 50 |
| | 3 knots | 100 |
| | | 75 |
| astern | near bollard | 100 |
| | | 75 |
| | | 50 |
| | 1.5 knots | 100 |
| | | 75 |

The parameters measured during the tests will be:

1. Below water flow observations along the hull
2. Above water flow observations in the stern area

3. Shaft thrust
4. Shaft torque
5. Nozzle thrust
6. Power delivered to the motor
7. RPS

9. Current ice coverage (by means of the camera)

10. Ship speed (carriage speed)

### 2.3.6. Summary of ice flow tests (all values full scale)

| test | ice condition | | | | ship condition | | | |
|---|---|---|---|---|---|---|---|---|
| # | thickn | size | cover | feature | speed | power | draft | influence |
| - | m | m^2 | % | - | kn | % | % | |
| 1 | 0.6 | 20 | 100 | level | +3 | 100 | 100 | influence of speed |
| 2 | 0.6 | 20 | 100 | level | +5 | 100 | 100 | |
| 3 | 0.6 | 20 | 100 | level | +1 | 100 | 100 | |
| 4 | 0.6 | 20 | 100 | level | -0.5 | 100 | 100 | |
| 5 | 0.6 | 20 | 100 | level | -1 | 100 | 100 | |
| 6 | 0.6 | 20 | 100 | level | -2 | 100 | 100 | |
| 7 | 0.6 | 20 | 100 | level | 3 | 75 | 100 | influence of power level |
| 8 | 0.6 | 20 | 100 | | 1 | 75 | | |
| 9 | 0.6 | 20 | 100 | | 1 | 50 | | |
| 10 | 0.6 | 20 | 100 | | -0.5 | 75 | | |
| 11 | 0.6 | 20 | 100 | | -0.5 | 50 | | |
| 12 | 0.6 | 20 | 100 | | -1.5 | 75 | | |
| 13 | 0.6 | 20 | 100 | | -1.5 | 50 | | |
| 14 | 0.6 | 20 | 100 | level | 3 | 100 | 80 | influence of draft |
| 15 | 0.6 | 20 | 100 | | -1.5 | 100 | 60 | |
| 16 | 0.6 | 20 | 100 | | -1.5 | 100 | trim* | |
| 17 | 0.6 | 20 | 90 | | 3 | 100 | 100 | influence of coverage |
| 18 | 0.6 | 20 | 60 | | 3 | 100 | 100 | |

* optional

The above schedule may be modified if the results of the first test series are different from those expected.

Tests 1 to 18 are to be conducted over two days and the third day is assigned to reruning of some experiments and/or optional tests. Optional tests will include the ice thickness and ice configuration influence tests. Details are to be determined after the first tests is completed.

## 2.4. ICE SUCTION FORCES TESTS

Ice pieces blocking the nozzle most frequently during the first test series will be analyzed in terms of the forces acting upon them just prior and during the blockages.
Individual pieces will be suspended on the instrumented rod and the suction forces acting upon them and on the propulsion train will be determined as a function of various ship, ice and configuration parameters. Prior to each propulsion test run, experiments with the motor shut off will be made in order to determine drag forces acting on an ice piece due to ship motion.

*These tests will be made during remaining two days in the tank.*

*The following tests will take place:*

| *test* | *ice parameters* | | | *ship parameters* | | | *position* |
|---|---|---|---|---|---|---|---|
| *# -* | *thick m* | *size m^2* | *shape* | *speed kn* | *power %* | *draft %* | *vis a vis nozzle* |
| *1* | *1* | *20* | *rhomb* | *3* | *100* | *100* | *touching btm* |
| *2* | | | | *3* | *100* | *100* | *touching side* |
| *3* | | | | *3* | *100* | *100* | *touching top* |
| *4* | *1* | *20* | *rhomb* | *3* | *75* | *100* | *touching btm* |
| *5* | *1* | *20* | *rhomb* | *1* | *100* | *100* | *touching btm* |
| *6* | *1* | *20* | *rhomb* | *-0.5* | *100* | *100* | |
| *7* | *1* | *20* | *rhomb* | *-1* | *100* | *100* | |
| *8* | *1* | *20* | *rhomb* | *-2* | *100* | *100* | |
| *9* | *1* | *20* | *rhomb* | *5* | *100* | *100* | |
| *10* | | | | *0.5* | *100* | *100* | |
| *11* | | | | *10.0* | *100* | *100* | |
| *12* | | | | *3* | *50* | *100* | |
| *13* | | | | *-1* | *75* | *100* | |
| *14* | | | | *3* | *100* | *100* | |
| *15* | | | | *3* | *100* | *100* | |
| *16* | *1* | *20* | *rhomb* | *3* | *100* | *100* | *1m away* |
| *17* | | | | *3* | *100* | *100* | *2m away* |
| *18* | | | | *3* | *100* | *100* | *3m away* |

*If time will permit, the optional tests will be conducted dealing with the influence of ice thickness and geometry on the suction forces.*

## *2.6. MODIFIED DESIGN TESTING*

*After completing the analysis of the test results, the stern area and the nozzle will be modified in order to prevent blockage from occurring frequently and also to minimize the effects of the blockage on the propeller.*

*A modified configuration will be tested in the basin at the same conditions as some of the previous tests.*

*The following runs will be executed:*

| ICE FLOW TESTS | ICE SUCTION TESTS |
|---|---|
| #1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 6 |
| 5 | 7 |
| 6 | 8 |
| 10 | 11 |
| 13 | 18 |

*TO BE DETERMINED DURING THE TESTS*

*This test series will last approximately five days.*

*Instrumentation, calibration and execution of these tests will be the same as during the first test series.*

## 3. INSTRUMENTATION

The experiments will be conducted in a clear water tank of the IMD, St John,s, Newfoundland. Routinely used instrumentation will be employed to conduct the experiments.

Microcomputer VAX-2 AND THE SOFTWARE PACKAGE DAS-ACQUIRE will be used to collect and store test data on a hard disk.

32 channels will be sampled during the tests. The software package will be used to make on-line tests analysis.
SOFTWARE PACKAGE RST/TSA will be used to conduct analysis of the tests.

Shaft torque and thrust signals will be measured by a dynamometer type R33 Nr234, 15Nm/400N, Kempt and Remmers.

An electric motor PMF MC24P will be used to supply power to the propellers.

Nozzle and rod gauge will be instrumented with a transducer consisting of a four-bridge configuration of electrical resistance strain gauges to measure nozzle forces and ice sucking forces.

## 4. CALIBRATION

Software package CAL and MICRO VAX-2 will be used to calibrate particular channels by applying known static values of forces and moments as a function of current/voltage and a straight line data will be fitted using the least square technique. All sensors will be calibrated before tests and some will be recalibrated during the tests as required.

## 5. EQUIPMENT

Principal equipment used during the tests is shown in Figure 1.

## 6. DATA TO BE COLLECTED

THE FOLLOWING IS A LIST OF SIGNALS AND OTHER DATA TO BE COLLECTED DURING THE TESTS:

| ENGINEERING QUANTITY | SIGNAL FORMAT |
|---|---|
| 1. Ship speed | DIGITAL |
| 2. Shaft RPM | DIGITAL |

|  |  |
|---|---|
| *3. Shaft torque* | *DIGITAL* |
| *4. Shaft thrust* | *DIGITAL* |
| *5. Nozzle thrust* | *DIGITAL* |
| *6. Ice suction force* | *DIGITAL* |
| *7. Above water video.* | *TAPE* |
| *8. Below water video.* | *TAPE* |
| *9. Ship draft* | *MEASUREMENT.* |
| *10. Time base* | *DIGITAL* |

*DERIVED QUANTITIES*

*Shaft power*

*Frequency of Interaction*

*Severity of blockage*

*Ice spatial coverage*

*Ice flux thru disk area*

*Water drag of ice pieces.*

## *7. FORMAT OF THE RESULTS*

*All data collected in the model basin will be stored in a magnetic disk/tape format.*

*The analysis of the data will be conducted using paper copies of the most relevant recordings and events, in order to illustrate the issue at hand.*

*The derived relationships and correlations will be presented in a graphical form.*

*The bulk of the data will be contained in the APPENDICES. The MAIN REPORT will contain the most relevant examples of the data.*

*The results of the data analysis will be presented in a graphical form*

# APPENDIX C

## DETAILED LITERATURE REVIEW

*SUBJECT: PROPELLER NOZZLE APPLICATION*

*AUTHORS: LASKOW, V.*

*TITLE: PROPELLER NOZZLE APPLICATION INVESTIGATION*

*SOURCE: ARAD REPORT TO CCG FLEET SYSTEMS*
*DATED: 31/3/87*

*REVIEWED BY: V. LASKOW.....................DATE: 12/87...........*

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## *ABSTRACT*

*This report investigates the potential application of a shrouded propeller installation on the centerline shaft of the CCGS LOUIS S.ST LAURENT. The cavitation issue is addressed in detail, as is the performance of the shrouded propeller measured against the open one. The optimum design of the shrouded propeller is obtained by means of the computer optimization programme. The strength of the nozzle for icebreaking duties is assessed, as is the cost of fabrication and installation. Pros and cons of such a choice are discussed in detail, in particular the potential of nozzle blockage.*

---

## *RELEVANT FINDINGS*

1. *Fittment of the shroud on the centerline shaft of LSSL is feasible and advantageous.*
2. *Shrouded propeller will experience less cavitation than the open one.*
3. *Shrouded propeller will significantly outperform the open one in all performance criteria specified by CGS, except at a high speed free running condition.*
4. *The potential for frequent blockage of the shroud is small, due to the deep draft of the ship and the presence of wing propellers.*

---

## *COMMENTS*

*This report formed the basis for the recommendation of the fittment of the shroud on the centerline shaft of CCGS LSSL. Subsequent to this report, the present investigation was undertaken and partially sponsored by CCG FLEET SYSTEMS.*

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..........................................................
..........................................................

SUBJECT: STRENGTH REQUIREMENTS FOR NOZZLES

AUTHORS: LASKOW, V., REVILL, C.

TITLE: STUDY OF STRENGTH REQUIREMENTS FOR NOZZLES OF ICE TRANSITING SHIPS

SOURCE: TDC REPORT TP6837E
DATED: 1/7/85

REVIEWED BY: V. LASKOW....................DATE: 12/87............

## ABSTRACT

This report investigates the strength requirements for the shrouds of icebreaking vessels. The state of the art in shrouded propeller applications on icebreaking vessels is reviewed and analyzed. A number of nozzle/ship/ice interaction scenarios are developed and a computerized simulation of ice impacts on the nozzle is run, producing the interaction forces. A series of shrouds was designed having the standard NSMB nozzle as a basis and progressively thicker profiles for heavier icebreaking duties.

The strength of this design series is investigated in detail, as is its hydrodynamic performance. Detailed analysis of the stresses and strains on the nozzle ring are performed for the different geometries of ice force (radial and axial loads) and different nozzle support configurations. A formula is developed linking the global and local strength requirements with the ice class, size and power of ships. This formula is a basis for the proposed ASPPR regulations.

## RELEVANT FINDINGS

1. There is a growing tendency to use shrouded propellers in icebreaking ships.
2. Shrouds can be built strong enough to sustain anticipated ice loads, provided the supports are properly designed.
3. Higher the ice class, wider the foundation should be.
4. Thicker nozzle profiles assure the adequate strength without compromising on the nozzle weight or performance.
5. Presently fitted nozzles are of adequate strength, except for the MV ARCTIC.

## COMMENTS

The report recommends a number of regulatory measures for nozzle safety assurance. To complement the work done to date, a full scale calibration programme is recommended. The report concludes that the nozzles can be built with adequate strength for ice.

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SUBJECT: ICE/PROPELLER INTERACTION

AUTHORS: LASKOW, V., SPENCER, P., KIRBY, K.

TITLE: ROBERT LEMEUR ICE/PROPELLER INTERACTION - 1985 FINAL REPORT

SOURCE: TDC REPORT TP6176/77/78
DATED: 1/4/85

REVIEWED BY: V. LASKOW......................DATE:12/87...........

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## ABSTRACT

This report details two phases of a large project aimed at the gathering and analysis of the ice/propulsion interaction data; pretesting and full scale testing of the propulsion train of MV ROBERT LEMEUR. Pretesting included an extensive calibration of all of the instrumentation used. Two full scale data sets were gathered: Those conducted during the 4 days of dedicated tests and those collected during the whole operating season of the ship. Instrumentation of the propulsion train included; BLADE BENDINg,BLADE SPINDLE TORQUE, SLIDING BLOCK FORCE, SERVO OIL PRESSURE, SHAFT TORQUE, SHAFT THRUST, RPM, SHAFT POSITION IN THE BEARING, SHIPS SPEED, FUEL RACK AND RUDDER ANGLE. A data set comprised of 343 detailed 7 sec duration events has been compiled together with the statistics of the season's operations.

## RELEVANT FINDINGS

1. The most important finding of this project was that blockages of the shroud produced very high loads on the propulsion train and the propeller of MVRL, the magnitude of which are only a few percent lower than the loads due to direct ice impacts.
2. Blockage loads last for many seconds, depending on the severity of the vibrations, and the response time of the propeller to the pitch reversal command.
3. Blockages lead to very fluctuating loads on the blade and propulsion trains, in particular spindle torque and sliding block forces.

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## COMMENTS

The report gives the detailed and broad basis for the analysis of the ice/propeller interaction, unprecedented in the history of icebreaking shipping. A great many important conclusions will be derived based on the finding from the programme described in the report.

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SUBJECT: ICE/PROPELLER INTERACTION

AUTHORS: LASKOW, V., REVILL, C.

TITLE: ENGINEERING ANALYSIS OF ICE/PROPELLER INTERACTION DATA

SOURCE: TDC REPORT TP
DATED: 1/7/87

REVIEWED BY: V. LASKOW.......................DATE: 12/87..........

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## ABSTRACT

This report details the engineering analysis of the full scale data collected onboard MV ROBERT LEMEUR, for the purpose of developing new design and regulatory requirements for the propellers of icebreaking ships. A detailed literature search, data compilation and review of the existing ice/propeller interaction model of shrouded and open propellers is performed. Based on the experience and data from MV ROBERT LEMEUR, formulas for the prediction of ice induced blade and shaft forces and torques are derived for the shrouded CPP. The influence of the duration of the testing period and the prevalent ice conditions is established. A computerized model of the shaftline is employed in order to assess the transfer function between the load on the tip of the propeller and the reading of the shaft strain gauges. The influence of the shaft characteristics and propulsion control schemes in investigated by means of parametric variation. Proposed design procedures and regulations for the strength of the blade for shrouded CPP are developed.

---

## RELEVANT FINDINGS

1. Maximum blade forces do not occur at the same time as the maximum shaft torques and thrusts.
2. Hydrodynamic loads acting on the shrouded propellers are as high and frequent as direct ice impact loads.
3. Present state of the art in predicting ice/propeller interaction forces is highly inadequate.
4. Duration of the ship operations has little influence on the magnitude of ice induced maximum shaft torques and thrusts, in ahead operations.
5. Ice induced torques and thrusts acting on the shrouded propellers are lower than those induced on the open ones.
6. Present blade strength levels of shrouded CPPS are not adequate.
7. Proposed design changes will strengthen the blades without necessitating any changes to the propulsion shafting strength requirements.

---

## COMMENTS

This report is a first attempt in Canada to rationalize icebreaking propeller design criteria based on full scale data.

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*SUBJECT: FULL SCALE DATA COLLECTION*

*AUTHORS: LASKOW, V., SPENCER, P., BAYLEY, I.M.*

*TITLE: MV ROBERT LEMEUR ICE/PROPELLER INTERACTION - FULL SCALE DATA*

*SOURCE: SNAME MARINE TECHNOLOGY.................................*
*DATED: 1/10/86*

*REVIEWED BY: V. LASKOW......................DATE: 12/87..........*

## *ABSTRACT*

*This paper summarizes the main findings of the full scale data collection programme executed during the years 1983/1984 for the TDC. The instrumentation used, installation and calibration of the instrumentation is described in detail. Four day testing as well as long term seasonal shaft statistics are described. The main findings are listed and the differences with the present state of the art knowledge of ice loads on the propellers are discussed. Typical and extreme ice/propeller interaction events are shown and discussed.*

## *RELEVANT FINDINGS*

*1.Hydrodynamic loads due to blockage are of equal magnitude to those imposed by direct impact.*
*2.Magnitudes of ice induced thrust are over four times those calculated for the bollard condition.*
*3.Blockages induce severe vibrations and load fluctuations inside the CPP pitch changing mechanism.*
*4.Maximum loads on the blade of the 3M diameter propeller of MV ROBERT LEMEUR were 375KN.*
*5.Early season icebreaking operations result in the very high loads on propellers. Whole season operations give only marginally higher loads than those developed during the early season's four days of operations.*

## *COMMENTS*

*This paper is a concise account of the many important finding on the ice/shrouded CPP interaction during the early season and whole 1984 season of operations of icebreaking supply ship MV ROBERT LEMEUR.*
*THE PAPER RECEIVED THE ADM COCHRANE AWARD FOR THE BEST SECTION PAPER IN 1985.*
*.........................................................................*

SUBJECT: MODELING

AUTHORS: LASKOW, V.

TITLE: MODELING THE BROKEN CHANNEL

SOURCE: ACL REPORT TO CCG NORTHERN
DATED: 31/3/84

REVIEWED BY: V. LASKOW......................DATE: 12/87..........

## ABSTRACT

This report details an analytical and full scale investigation into the problem of sizing of ice broken by an icebreaking ship. Initially the theoretical size of the broken piece is established using the principle of the characteristic length of beams resting on elastic foundations. Secondly, the size of the broken pieces from the channel of MV CANMAR KIGORIAK were measured and statistically assessed. The discrepancy found was approximately 10 fold. Finally a series of model tests in saline and wax ice were performed and sizes of broken pieces measured and analyzed. The large discrepancy between the full scale and model scale piece sizes were found.

---

## RELEVANT FINDINGS

1. Sizes of broken pieces in full scale are 10 times smaller than those predicted by the elastic bending theory.
2. Size of the broken pieces vary across the channel and along the channel, larger being at the edge of the channel.
3. Full scale sizes are several times smaller than those obtained in the model scale tests in saline or wax ice.
4. Was ice produced more realistic sizes than saline ice.
5. The modeling of the breaking pattern and the understanding of it is not adequate at the present time.

## COMMENTS

This investigation was prompted by the inadequate model testing techniques, often leading to erroneous conclusion. This project was a first attempt in Canada to correlate the theory, experiments and full scale data on the sizes of broken ice pieces in the channel of an icebreaker.

*SUBJECT: ICE/PROPELLER INTERACTION*

*AUTHORS: DUFF,.J., KIRBY, K., LASKOW, V.*

*TITLE: MEASUREMENT OF ICE/PROPELLER INTERACTION PARAMETERS -*
*MV ROBERT LEMEUR*

*SOURCE: TDC REPORT TP6839E*
*DATED: 1/7/85*

*REVIEWED BY: V. LASKOW ..................DATE: 12/87.............*

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## *ABSTRACT*

*This report details the work done for TDC during the 1983 and 1984 period, including the full scale test of MV ROBERT LEMEUR. The instrumentation chosen, calibration used and the methods of signal interpretation are described in detail. Further, the typical and extreme data collected during the 1983 dedicated trials and full season of operations is catalogued and reduced to engineering units. Full scale trials are described in detail, including ice conditions. Ice/propeller interaction events are statistically analyzed and displayed using specially developed software. Signals are sorted and the bad ones are eliminated. Brief models of ice/propeller interaction are developed, together with the blade response model and the shaftline model to be used for future detailed analysis of the data.*

---

## *RELEVANT FINDINGS*

1. *Blockage induced loads are of magnitudes equal to those due to the direct ice impact.*
2. *There is a large number of ice propeller interactions taking place in spite of the many design precautions taken.*
3. *The gauges placed on the propeller blade and inside the hub worked satisfactorily with small exceptions.*
4. *The magnitudes of the ice induced loads on the propeller and propulsion train exceed by far those indicated by the present state of the art understanding of the problem.*
5. *Data collected contradicted in many instances the up to date understanding of the phenomena taking place.*

---

## *COMMENTS*

*Preliminary findings of this project indicated that much is to be learned from the data collected. Further signal analysis and in depth interpretation of the data is needed to verify the correctness of the preliminary startling conclusion.*

SUBJECT: ICE/PROPELLER INTERACTION

AUTHORS: LASKOW, V., KIRBY, K., REVILL, C.

TITLE: SUPPLEMENT TO FINAL REPORT ON THE MEASUREMENTS OF ICE/PROPELLER INTERACTION

SOURCE: TDC REPORT TP
DATED: 1/9/86

REVIEWED BY: V. LASKOW....................DATE: 12/87.............

## ABSTRACT

This supplement was developed in order to confirm, or negate the startling conclusions from the full scale test of MV ROBERT LEMEUR (SEE PREVIOUS ABSTRACTS). The items in question were shaft thrust, location of ice force vector in the blade, shaft proximity probes readings, and sliding force magnitude and direction. In addition, the blockage forces and thrusts were looked at in detail. The questionable signals were check and double checked, using the calculations, other gauges and simple analytics. The results showed that the gauges were reporting correctly the unknown phenomena, except for some thrust gauges which were identified and eliminated. A list of reliable readings was produced. The main findings from the previous report were upheld.

## RELEVANT FINDINGS

1. High torques and thrusts are developed during the blockages in spite of a significant reduction of propeller pitch.
2. Propeller develops a very high thrust, while the nozzle does not.
3. Shaft of the MV ROBERT LEMEUR operates in a condition contrary to the one expected using the hydrodynamic lubrication theory.
4. During the blockage,large fluctuations of sliding block forces take place.
5. Blockages produce the highest thrusts, in spite of the significant pitch reductions.

## COMMENTS

Verification of the previously reported findings was positive. In particular the behavior of the thrust, torque and sliding block forces during the blockage events was confirmed, pointing towards the new and important phenomena. Severe vibrations during the blockage may lead to the fatigue strength problems.

SUBJECT: PROPULSION/ICE INTERACTIONS

AUTHORS: KEINONEN, A., LASKOW, V., REVILL, C.

TITLE: SHIP PROPULSION/ICE INTERACTION STUDY: A COMPARISON OF FULL SCALE

SOURCE: TDC REPORT TP
DATED: 12/12/87

REVIEWED BY: V. LASKOW.....................DATE: 12/87...........

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## ABSTRACT

This report compares the results of the full scale trials of MV ROBERT LEMEUR and the icebreaking cutter MV JARVSAAR. Further, the analytical models derived from LEMEUR data are compared with the JARVSAAR data. Ice induced nozzle forces and the propeller shaft thrusts and torques are compared. A number of actual ice/propeller and nozzle interactions are analyzed in some detail. Open propeller and shrouded propeller ice interactions are compared . The influence of the pitch setting, rpm and speed on the operations of the ship is assessed.

---

## RELEVANT FINDINGS

1. Analytical models developed from ROBERT LEMEUR data were confirmed by JARVSAAR full scale data.
2. Analytical models developed from other ships data (OPEN FIXED PITCH ELECTRIC TRANSMISSION) were not confirmed.
3. Blockages of JARVSAAR propeller occur most frequently during astern operation of the ship.
4. Blockages of JARVSAAR propeller occur most frequently during astern operations of the ship.
5. A number of significant conclusions were arrived at, but those cannot be quoted here due to the pendant confidentiality clause.

---

## COMMENTS

Good correlation of JARVSAAR data with the LEMEUR data and the subsequent models provides the basis for further modeling work, in particular the modeling of the blockage phenomenon. This problem needs to be resolved now.
A large discrepancy between the JARVSAAR shaftline signals and those reported elsewhere indicate that the type of propulsion controls, transmission system and propeller play a significant role in determining the magnitudes of ice-induced loads.

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SUBJECT: HYDRODYNAMIC LOADS

AUTHORS: LINDROOS, H., BJORKESTAM, H.

TITLE: HYDRODYNAMIC LOADS DEVELOPED DURING ICE-CLOGGING OF A PROPELLER

SOURCE: POAC '86
DATED: 1/1/86

REVIEWED BY: V. LASKOW......................DATE: 12/87.........

## ABSTRACT

This paper summarizes the research done in Finland on the blockages of shrouded propellers. Two types of data were gathered: full scale tests of small cutters (JARVSAAR AND MATARI) and the cavitation tunnel systematic test series with blocked nozzle. Details of the model test experiments are given. The parameters varied were: Blockage Ratio, Advance Coefficient, and Cavitation number. The parameters measured were shaft thrust, torque and bending moment, nozzle thrust, blade bending moment and spindle torque. The influence of the blockage on these parameter is discussed. Comparison between the experiments by VALMET, those by Russians and full scale data is given.

## RELEVANT FINDINGS

1. Blockages increase substantially the blade loads and shaft torques and thrust. They decrease nozzle loads. These increases are of the order of several hundred percent for the average values, but several thousand percent for the peak values.
2. The most significant increases were of the spindle torques.
3. The experiments conducted by VALMET correlate well with those done by the Russians and the full scale trends.
4. Of the means for blockage prevention, a diverted flow nozzle (SLOTTED NOZZLE) was chosen for the model test.
5. The results of these tests show that the slotted nozzle alleviates the severity of blockage forces'' fluctuations somewhat.

## COMMENTS

The paper is very brief and does not do justice to the research effort. Many important parameters are missing from the test setup description (POWER LEVEL, RPM ETC). A more detailed description is needed as well as more of the justification of the conclusion..

*SUBJECT: ICE INTERACTIONS*

*AUTHORS: KOCHEROV,P., TISHKOVETS, I.*

*TITLE: FROM THE EXPERIENCE OF BUILDING ICEBREAKING TUGS*

*SOURCE: SUDOSTROENIE #8*
*DATED:*

*REVIEWED BY: V. LASKOW ....................DATE: 12/87...........*

## *ABSTRACT*

*This paper describes the construction and operational experiences with the icebreaking harbor tugs delivered in the periods of 1951 (original designs) and 1955-1956(modified designs). The original designs had fixed pitch propeller and nozzle fittings. Severe damages were occurring to both the propeller and the nozzle as a result of frequent ice ingestion. Details of these damages are described.*

*In order to alleviate the problems, stronger propellers, reinforced nozzles and the specially designed grills were fitted in order to deflect ice from the propellers in ahead mode of operation. Those measures were proven to be very successful. The performance of the difference propeller types was also assessed thru the full scale trials, in order to compensate for the thrust deficiency. The optimum propeller was selected for future applications.*

## *RELEVANT FINDINGS*

1. *Blockages of shallow draft ships are frequent and severe.*
2. *Unprotected and unstrenghtened propellers and nozzles can be severely damaged by ice.*
3. *Fittment of steel cage in front of the nozzle for ice deflection is an effective means of propeller and nozzle protection. It does not lead to significant loss of performance.*
4. *The propeller which produces the highest thrust is not of the Kaplan Type, for that particular application.*

## *COMMENTS*

*This paper is the first known to the author reporting on the blockages and damages of shrouded propellers in full scale. A wealth of information is presented in a comparative fashion. Conclusions derived by the authros of the paper were later on confirmed by other investigators.*

SUBJECT: ICE FLOW UNDER THE HULL AND INTO THE PROPELLERS

AUTHORS: ARCTEC CANADA LTD.

TITLE:

SOURCE: TRANSPORT DEVELOPMENT CENTRE REPORT
DATED: 1984

REVIEWED BY: V. LASKOW......................DATE:.12/87..........

## ABSTRACT

The report summarizes the results of the study undertaken to identify and qualitatively evaluate the factors which contribute to the movement of broken pieces to the propeller, and discusses the effectiveness of modeling the phenomenon and the requirements to measure the effect. A comprehensive literature search was conducted, yielding little information on the topic. Information on the analysis of the factors influencing ice ingestion to the propellers was performed and these factors prioritized. Modeling of the broken channel problems is discussed. Methods of measuring the trajectories of the broken pieces are then presented.

## RELEVANT FINDINGS

1. There is not enough evidence and there is little understanding of the ice suction phenomenon.
2. Present model testing techniques are not adequate in this respect.
3. There is an urgent need to gather full scale data and gain some understanding of the problem.
4. There appears to be a maximum speed and a maximum power setting beyond which ice ingestion into the propeller ceases to be noticeable, for some ships operating in the Beaufort Sea.
5. Factors influencing the ice ingestion into the propellers are, arranged in the order of priority: ship overall geometry, bow geometry, ice conditions, and mode of operation.
6. Technology exists for accurate measurements of full scale broken pieces trajectories.

## COMMENTS

This work is of a general review type, pointing towards the necessity of further laboratory and full scale testing in order to gain some understanding of the problem.

# APPENDIX D

## DETAILED FLOATUP TESTS DATA

TABLE...

SUMMARY OF FLOAT-UP TESTS

| | DEPTH IN METE | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | 1.10 | 1.20 | 1.30 | 1.40 | 1.50 | 1.60 | NR OF TESTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TIME | 1.11 | 1.75 | 2.11 | 3.12 | 3.57 | 4.05 | 4.71 | 5.35 | 5.82 | 6.33 | 6.30 | 7.70 | 8.55 | 8.60 | 9.70 | 9.11 | 16 |
| | SECS | 1.17 | 1.87 | 2.11 | 3.18 | 3.70 | 4.23 | 4.70 | 5.59 | 5.96 | 6.35 | 6.48 | 7.12 | 8.56 | 8.41 | 9.64 | 9.13 | 16 |
| | | 1.29 | 1.75 | | | | 4.00 | | 5.28 | | 6.50 | 8.16 | | | | 9.52 | 9.52 | 8 |
| #1 | | 1.02 | 1.87 | | | | 4.22 | | 5.05 | | 5.97 | 8.29 | | | | 9.62 | 9.62 | 8 |
| FFU | | | | | | | | | 5.33 | | 6.23 | 7.43 | | | | | 10.59 | 4 |
| | | | | | | | | | 5.54 | | 6.36 | 7.49 | | | | | 10.49 | 4 |
| | | | | | | | | | | | 6.37 | | | | | | | 1 |
| | AVERAGE | 1.15 | 1.81 | 2.11 | 3.15 | 3.63 | 4.13 | 4.71 | 5.36 | 5.89 | 6.30 | 7.36 | 7.41 | 8.55 | 8.50 | 9.62 | 9.74 | |
| | | | 2.37 | | 1.38 | | 1.76 | | 2.29 | | 2.73 | | 5.11 | | 5.87 | | 7.76 | 8 |
| | | | 2.20 | | 1.41 | | 1.61 | | 2.12 | | 2.48 | | 5.25 | | 5.85 | | 7.58 | 8 |
| | | | | | 1.69 | | | | | | 2.60 | | 5.00 | | | | 7.37 | 4 |
| #1 | | | | | 1.61 | | | | | | 2.60 | | 5.10 | | | | 7.78 | 4 |
| LEU | | | | | | | | | | | | | | | | | | |
| | AVERAGE | | 2.29 | | 1.52 | | 1.69 | | 2.21 | | 2.60 | | 5.12 | | 5.86 | | 7.62 | |
| #1 | | | | 3.63 | | | | | | | | | | | | | | 1 |
| SEU | | | | 3.71 | | | | | | | | | | | | | | 1 |
| | | | | 4.00 | | | | | | | | | | | | | | 1 |
| | | | | 3.45 | | | | | | | | | | | | | | 1 |
| | AVERAGE | | | 3.70 | | | | | | | | | | | | | | 1 |
| #2 | | | | | | | | | | | | | | | | | | |
| FFU | | | 1.83 | | 2.78 | | 4.14 | | 5.06 | | 5.85 | | 6.74 | | 8.21 | | 8.62 | 8 |
| | | | 1.54 | | 2.76 | | 4.24 | | 5.37 | | 5.73 | | 6.74 | | 8.22 | | 8.30 | 8 |
| | | | 1.64 | | | | | | 5.56 | | 6.15 | | | | 8.21 | | 8.93 | 5 |
| | | | 1.71 | | | | | | 5.71 | | 6.32 | | | | 8.19 | | 9.10 | 5 |
| | | | | | | | | | | | 6.17 | | | | | | | 1 |
| | | | | | | | | | | | 6.25 | | | | | | | 1 |
| | AVERAGE | | 1.68 | | 2.77 | | 4.19 | | 5.42 | | 6.08 | | 6.74 | | 8.21 | | 8.74 | |
| #2 | | | | | | | | | | | | | | | | | | |
| LEU | | | | | | | | | | | | | | | | | 3.21 | 1 |
| | | | | | | | | | | | | | | | | | 3.62 | 1 |
| | | | | | | | | | | | | | | | | | 5.14 | 1 |
| | AVERAGE | | | | | | | | | | | | | | | | 3.99 | |
| #2-1 | | | 2.30 | | | | | | | | | | | | | | | 1 |
| LEU | | | 2.37 | | | | | | | | | | | | | | | 1 |
| | AVERAGE | | 2.33 | | | | | | | | | | | | | | | |
| | | 0.94 | 1.19 | 1.86 | 1.91 | | 2.96 | | 3.38 | | 4.16 | | 4.96 | | 5.67 | | 6.14 | 10 |
| #3 | | 0.60 | 1.57 | 1.69 | 2.00 | | 2.89 | | 3.41 | | 4.14 | | 5.25 | | 5.91 | | 6.07 | 10 |
| FFU | | 1.08 | 1.57 | | 1.92 | | | | 3.57 | | | | 4.91 | | | | 6.02 | 6 |
| | | 0.97 | 1.40 | | 1.83 | | | | 3.28 | | | | 5.00 | | | | 6.37 | 6 |
| | | 0.89 | | | | | | | | | | | | | | | | 1 |
| | AVERAGE | 0.90 | 1.43 | 1.77 | 1.92 | | 2.92 | | 3.41 | | 4.15 | | 5.03 | | 5.79 | | 6.15 | |
| | | | | | | | | | | | | | | | 5.84 | | 5.51 | 2 |
| #4 | | | | | | | | | | | | | | | 5.88 | | 5.70 | 2 |
| FFU | | | | | | | | | | | | | | | 5.53 | | 6.08 | 2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 5.72 | 6.07 | 2 |
| | | | | | | | | 5.56 | 6.19 | 2 |
| AVERAGE | | | | | | | | 5.74 | 5.89 | |
| | 1.31 | 1.43 | 2.29 | 3.30 | 4.20 | 5.26 | 5.94 | 7.18 | 7.96 | 9 |
| #4-1 | 1.15 | 1.65 | 2.54 | 3.42 | 4.52 | 5.52 | 5.86 | 7.40 | 8.10 | 9 |
| FFU | 0.93 | 1.48 | 2.78 | | | | 6.27 | | 7.96 | 5 |
| | 1.05 | 1.52 | 2.98 | | | | 6.52 | | 7.86 | 5 |
| | | | 2.40 | | | | 6.32 | | | 2 |
| | | | | | | | 6.57 | | | 1 |
| AVERAGE | 1.11 | 1.52 | 2.60 | 3.36 | 4.36 | 5.39 | 6.25 | 7.29 | 7.97 | |
| | 0.74 | 1.19 | 2.28 | 2.97 | 3.63 | 4.20 | 5.01 | 6.17 | 6.41 | 9 |
| #5 | 0.87 | 1.34 | 2.37 | 2.91 | 3.79 | 4.43 | 5.37 | 6.21 | 6.53 | 9 |
| FFU | 0.82 | 1.36 | 2.13 | | 3.93 | 4.58 | 5.35 | | 6.74 | 7 |
| | 0.77 | 0.84 | 2.19 | | | 4.79 | 5.43 | | 6.84 | 6 |
| | | 1.44 | | | | | | | | 1 |
| | | 1.49 | | | | | | | | 1 |
| AVERAGE | 0.80 | 1.28 | 2.24 | 2.94 | 3.78 | 4.50 | 5.29 | 6.19 | 6.63 | |
| | 1.14 | 1.35 | 3.00 | 4.14 | 5.28 | 5.88 | 7.37 | 8.52 | 9.60 | 9 |
| #6 | 1.29 | 1.59 | 3.07 | 4.33 | 5.23 | 6.08 | 7.07 | 8.21 | 9.65 | 9 |
| FFU | 1.16 | | | | 5.35 | 6.38 | 7.22 | 8.15 | | 5 |
| | 1.13 | | | | 5.14 | 6.80 | 7.42 | | | 4 |
| | | | | | | 6.82 | | | | 1 |
| | | | | | | 6.78 | | | | 1 |
| AVERAGE | 1.18 | 1.47 | 3.04 | 4.23 | 5.25 | 6.46 | 7.27 | 8.29 | 9.63 | 16 |
| | | 2.48 | 5.50 | 7.31 | 9.75 | 13.45 | 15.62 | | | 6 |
| #7 | | 2.77 | 5.85 | 7.17 | 10.31 | 13.43 | 16.36 | | | 6 |
| FFU | | 2.49 | 4.69 | | 10.50 | 13.34 | 15.38 | | | 5 |
| | | 2.83 | 4.64 | | 10.78 | 13.40 | 15.43 | | | 5 |
| AVERAGE | | 2.64 | 5.17 | 7.24 | 10.34 | 13.40 | 15.70 | | | |
| | | 1.91 | 3.75 | 5.09 | 7.98 | 10.60 | 11.87 | 13.38 | 16.06 | 8 |
| #8 | | 1.74 | 3.47 | 5.42 | 7.78 | 10.49 | 11.33 | 13.35 | 15.85 | 8 |
| FFU | | 1.64 | 3.88 | 6.22 | 7.32 | | | | 15.80 | 5 |
| | | 1.77 | 4.49 | 6.42 | 6.99 | | | | 15.87 | 5 |
| AVERAGE | | 1.77 | 3.90 | 5.79 | 7.52 | 10.54 | 11.60 | 13.37 | 15.89 | |
| | | 1.16 | 2.95 | 4.16 | 7.81 | 8.23 | 10.90 | 12.50 | 13.30 | 8 |
| #9 | | 1.17 | 2.87 | 4.00 | 7.45 | 8.09 | 10.56 | 12.56 | 13.33 | 8 |
| FFU | | | | | | | | | | |
| AVERAGE | | 1.17 | 2.91 | 4.08 | 7.63 | 8.16 | 10.73 | 12.53 | 13.32 | GRAND |
| | | | | | | | | | | TOTAL |
| | | | | | | | | | | 337 |

# APPENDIX E

## DETAILED WATERJET TEST RESULTS

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ROUP NO.   1     TOTAL NO. OF SAMPLES =     862      29-MAR-1988 20:58:41
1 =    2.1200 SEC.     T2 =   16.9200 SEC.
ROJ. # R4034 NOZZLE JET FORCES
ED. NOZZLE. PERPENDIC. 0.5 M DEPTH, ZERO STATS

H DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

1 JET FORCE (N)                     -0.1680E-02  0.4997E-01 -0.1222E+00  0.1230E+0



ROUP NO.   2     TOTAL NO. OF SAMPLES =    3228      29-MAR-1988 21:03:51
1 =    9.9200 SEC.     T2 =   40.1000 SEC.

ROJ. # R4034 NOZZLE JET FORCES
ED. NOZ.,PERPENDIC. 0.5 M DEPTH, PRESS=2.0 BAR

H DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

1 JET FORCE (N)                      0.1262E+02  0.6762E+00  0.1078E+02  0.1442E+0



ROUP NO.   3     TOTAL NO. OF SAMPLES =    1665      29-MAR-1988 21:10:18
1 =    9.9400 SEC.     T2 =   30.0200 SEC.

ROJ. # R4034 NOZZLE JET FORCES
ED. NOZ., PERPENDIC. 0.5 M DEPTH, PRESS.=4.0 BAR

H DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

1 JET FORCE (N)                      0.2127E+02  0.8119E+00  0.1901E+02  0.2347E+0



ROUP NO.   4     TOTAL NO. OF SAMPLES =    1529      29-MAR-1988 21:15:45
1 =    4.9600 SEC.     T2 =   25.0400 SEC.

ROJ. # R4034 NOZZLE JET FORCES
ED. NOZ., PERPENDIC. 0.5 M DEPTH, PRESS.=4.8 BAR

H DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM
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1 JET FORCE (N)                            0.2482E+02  0.9112E+00  0.2187E+02  0.2752E+02



GROUP NO.   5     TOTAL NO. OF SAMPLES =      583     29-MAR-1988 21:19:23
T1 =    4.1600 SEC.      T2 =   10.9000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
REPEAT, MED. NOZ., 0.5 M DEPTH, PRESS.=2.0 BAR

CH DESCRIPTION                               AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                           0.9506E+01  0.5958E+00  0.8328E+01  0.1117E+02




GROUP NO.   6     TOTAL NO. OF SAMPLES =      727     29-MAR-1988 21:21:59
T1 =    2.4800 SEC.      T2 =   11.8600 SEC.

PROJ. # R4034 NOZZLE JET FORCES
   D. NOZ. PERPENDIC. 0.5 M DEPTH. PRESS.NOM.=1.2 BAR

CH DESCRIPTION                               AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                           0.8785E+01  0.4586E+00  0.7478E+01  0.9881E+01




GROUP NO.   7     TOTAL NO. OF SAMPLES =      296     29-MAR-1988 21:30:51
T1 =    0.1800 SEC.      T2 =    5.6200 SEC.

PROJ. # R4034 NOZZLE JET FORCES
LARGE NOZ., PERP. 0.5 M DEPTH, ZERO STATS

CH DESCRIPTION                               AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                           0.8078E-02  0.9649E-01 -0.1957E+00  0.2047E+00




GROUP NO.   8     TOTAL NO. OF SAMPLES =      490     29-MAR-1988 21:33:54
T1 =    1.6800 SEC.      T2 =    9.3800 SEC.

PROJ. # R4034 NOZZLE JET FORCES
LARGE NOZ. PERP. 0.5 M. DEPTH, PRESS.=0 NOM @ 63 Lt/MIN.
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DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

JET FORCE (N)                     0.7676E+01  0.4895E+00  0.6489E+01  0.8965E+01




UP NO.   9     TOTAL NO. OF SAMPLES =     718     29-MAR-1988 21:37:39
=    2.1800 SEC.     T2 =   13.8400 SEC.

J. # R4034 NOZZLE JET FORCES
GE NOZ. PERP. 0.5 M. DEPTH, PRESS.=0 NOM. MAX FLOW

DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

JET FORCE (N)                     0.2532E+02  0.8601E+00  0.2305E+02  0.2757E+02




UP NO.  10     TOTAL NO. OF SAMPLES =     493     29-MAR-1988 21:42:12
=    0.3600 SEC.     T2 =    9.8000 SEC.

J. # R4034 NOZZLE JET FORCES
NOZ., PERP. 0.5 M. DEPTH, ZERO STATS

DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

JET FORCE (N)                    -0.9675E-02  0.9572E-02 -0.3227E-01  0.2493E-01




UP NO.  11     TOTAL NO. OF SAMPLES =     473     29-MAR-1988 21:48:44
=    1.7200 SEC.     T2 =    9.1000 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. 0.5 M DEPTH, PRESS.=2.0 NOM.

DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM

JET FORCE (N)                     0.2809E+01  0.3685E+00  0.1627E+01  0.3588E+01




UP NO.  12     TOTAL NO. OF SAMPLES =     434     29-MAR-1988 21:50:42
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        0.4600 SEC.      T2 =    8.0600 SEC.

PROJ. # R4034 NOZZLE JET FORCES
Sm. NOZ. PERP. 0.5 M. DEPTH, PRESS.=4.0 BAR NOM.

CH DESCRIPTION                          AVERAGE       RMS         MINIMUM      MAXIMUM

 1 JET FORCE (N)                      0.5346E+01  0.4889E+00  0.4070E+01  0.6579E+01



GROUP NO.  13      TOTAL NO. OF SAMPLES =      423      29-MAR-1988 21:53:03
T1 =     1.1600 SEC.      T2 =    7.1600 SEC.

PROJ. # R4034 NOZZLE JET FORCES
Sm. NOZ. PERP. 0.5 M. DEPTH, PRESS.=6.0 BAR NOM.

CH DESCRIPTION                          AVERAGE       RMS         MINIMUM      MAXIMUM

   ET FORCE (N)                       0.7434E+01  0.4911E+00  0.6448E+01  0.8606E+01



GROUP NO.  14      TOTAL NO. OF SAMPLES =      562      29-MAR-1988 21:56:19
T1 =     1.3400 SEC.      T2 =   10.8400 SEC.

PROJ. # R4034 NOZZLE JET FORCES
Sm. NOZ. PERP. 0.5 M. DEPTH. PRESS.=6.2 BAR NOM.

CH DESCRIPTION                          AVERAGE       RMS         MINIMUM      MAXIMUM

 1 JET FORCE (N)                      0.7935E+01  0.4542E+00  0.6939E+01  0.8900E+01



GROUP NO.  15      TOTAL NO. OF SAMPLES =      778      29-MAR-1988 22:08:54
T1 =     0.5800 SEC.      T2 =    7.8200 SEC.

   J. # R4034 NOZZLE JET FORCES
    NOZ. PERP. 1.0 M. DEPTH, ZERO STATS

CH DESCRIPTION                          AVERAGE       RMS         MINIMUM      MAXIMUM

 1 JET FORCE (N)                     -0.2939E-02  0.2713E-01 -0.5679E-01  0.5762E-01
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UP NO.  15     TOTAL NO. OF SAMPLES =      778     29-MAR-1988 22:08:54
=    8.8600 SEC.      T2 =   15.2200 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. 1.0 M. DEPTH, ZERO STATS

DESCRIPTION                             AVERAGE        RMS       MINIMUM     MAXIMUM

JET FORCE (N)                       -0.3095E-02  0.1290E+00 -0.2529E+00  0.2456E+00



UP NO.  16     TOTAL NO. OF SAMPLES =      607     29-MAR-1988 22:11:47
=    1.3400 SEC.      T2 =    6.2000 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. 1.0 M DEPTH, PRESS.=2.0 BAR. NOM.

DESCRIPTION                             AVERAGE        RMS       MINIMUM     MAXIMUM

JET FORCE (N)                        0.2004E+01  0.2512E+00  0.1480E+01  0.2550E+01



UP NO.  17     TOTAL NO. OF SAMPLES =      553     29-MAR-1988 22:14:19
=    1.6800 SEC.      T2 =    8.3000 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. 1.0 M. DEPTH, PRESS.=4.0 BAR. NOM.

DESCRIPTION                             AVERAGE        RMS       MINIMUM     MAXIMUM

JET FORCE (N)                        0.3884E+01  0.4967E+00  0.2599E+01  0.4936E+01



UP NO.  18     TOTAL NO. OF SAMPLES =      606     29-MAR-1988 22:16:47
=    2.1000 SEC.      T2 =   10.9600 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. 1.0 M, DEPTH, PRESS.=6.0 BAR. NOM.

DESCRIPTION                             AVERAGE        RMS       MINIMUM     MAXIMUM
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 1 JET FORCE (N)                   0.5604E+01  0.7193E+00  0.4070E+01  0.7159E+



GROUP NO.  20     TOTAL NO. OF SAMPLES =     496     29-MAR-1988 22:24:46
T1 =    0.3200 SEC.     T2 =    9.6600 SEC.

PROJ. # R4034 NOZZLE JET FORCES
LARGE NOZ. PERP. 1.0 M. DEPTH. ZERO STATS.

CH DESCRIPTION                      AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                  -0.5280E-03  0.9298E-02 -0.3227E-01  0.3310E-



GROUP NO.  21     TOTAL NO. OF SAMPLES =     361     29-MAR-1988 22:26:58
T1 =    0.9400 SEC.     T2 =    5.8400 SEC.

PROJ. # R4034 NOZZLE JET FORCES
Lg. NOZ. PERP. 1.0 M. DEPTH, PRESS.=0.0 MAX FLOW.

CH DESCRIPTION                      AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                   0.1818E+02  0.2251E+01  0.1357E+02  0.2285E+



GROUP NO.  22     TOTAL NO. OF SAMPLES =     405     29-MAR-1988 22:31:49
T1 =    4.8200 SEC.     T2 =    7.7400 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED.NOZ. PERP. 1.0 M. DEPTH. ZERO STATS.

CH DESCRIPTION                      AVERAGE       RMS       MINIMUM     MAXIMUM

 1 JET FORCE (N)                   0.3417E-02  0.1220E+00 -0.1957E+00  0.2047E+



GROUP NO.  23     TOTAL NO. OF SAMPLES =     446     29-MAR-1988 22:34:00
T1 =    1.2600 SEC.     T2 =    8.7200 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. PERP. 1.0 M. DEPTH, PRESS.=2.0 BAR. NOM
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DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                        0.9398E+01  0.1081E+01  0.5696E+01  0.1217E+02



OUP NO.  24     TOTAL NO. OF SAMPLES =     341     29-MAR-1988 22:36:40
 =    1.0000 SEC.     T2 =    5.6600 SEC.

OJ. # R4034 NOZZLE JET FORCES
D. NOZ. PERP. 1.0 M. DEPTH, PRESS.=4.0 BAR. NOM.

DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                        0.1623E+02  0.1364E+01  0.1292E+02  0.1876E+02



OUP NO.  25     TOTAL NO. OF SAMPLES =     457     29-MAR-1988 22:39:30
 =    1.8200 SEC.     T2 =    8.6600 SEC.

OJ. # R4034 NOZZLE JET FORCES
D NOZ. PERP. 1.0 M. DEPTH. PRESS.=4.8 BAR.NOM.

DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                        0.1929E+02  0.2328E+01  0.1292E+02  0.2464E+02



OUP NO.  26     TOTAL NO. OF SAMPLES =     200     29-MAR-1988 22:47:26
 =    0.0800 SEC.     T2 =    3.8000 SEC.

OJ. # R4034 NOZZLE JET FORCES
D. NOZ. PERP. 0.2 M. DEPTH, ZERO STATS.

DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                       -0.7451E-02  0.6130E-01 -0.1058E+00  0.9031E-01



OUP NO.  27     TOTAL NO. OF SAMPLES =     382     29-MAR-1988 22:49:33
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T1 =    0.7400 SEC.      T2 =    7.3000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
  D. NOZ. PERP. 0.2 M. DEPTH, PRESS.=1.2 BAR. NOM.

CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                   0.8504E+01  0.2717E+00  0.7887E+01  0.9227E+01



GROUP NO.  28     TOTAL NO. OF SAMPLES =     375     29-MAR-1988 22:52:52
T1 =    1.1600 SEC.      T2 =    5.2000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. PERP. 0.2 M. DEPTH, PRESS.=2.0 BAR. NOM.

CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                   0.1233E+02  0.2935E+00  0.1170E+02  0.1308E+02



GROUP NO.  29     TOTAL NO. OF SAMPLES =     387     29-MAR-1988 22:54:58
T1 =    1.0600 SEC.      T2 =    7.6200 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. PERP. 0.2 M. DEPTH. PRESS.=4.0 BAR NOM.

CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                   0.2274E+02  0.3346E+00  0.2204E+02  0.2358E+02



GROUP NO.  30     TOTAL NO. OF SAMPLES =     553     29-MAR-1988 22:56:19
T1 =    0.7000 SEC.      T2 =    9.8400 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. PERP. 0.2 M. DEPTH, PRESS.=5.0 BAR NOM.

   DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                   0.2610E+02  0.4001E+00  0.2462E+02  0.2713E+02
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UP NO.  31     TOTAL NO. OF SAMPLES =     222     29-MAR-1988 23:16:43
=     0.2800 SEC.     T2 =    3.2000 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. OUT OF WATER ZERO STATS

DESCRIPTION                            AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                       -0.4039E-02  0.3015E-01 -0.8026E-01  0.6684E-01



UP NO.  32     TOTAL NO. OF SAMPLES =     353     29-MAR-1988 23:19:27
=     1.4800 SEC.     T2 =    4.9800 SEC.

J. # R4034 NOZZLE JET FORCES
 NOZ. PERP. ABOVE WATER, PRESS.=1.0 BAR

DESCRIPTION                            AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                         0.8708E+01  0.9852E+00  0.6678E+01  0.1117E+02



UP NO.  33     TOTAL NO. OF SAMPLES =     500     29-MAR-1988 23:21:40
=     4.6400 SEC.     T2 =    7.3600 SEC.

J. # R4034 NOZZLE JET FORCES
. NOZ. PERP. ABOVE WATER, PRESS.=2.0 BAR NOM.

DESCRIPTION                            AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                         0.1165E+02  0.1510E+01  0.9089E+01  0.1426E+02



UP NO.  33     TOTAL NO. OF SAMPLES =     500     29-MAR-1988 23:21:40
=     8.0200 SEC.     T2 =    9.8400 SEC.

J. # R4034 NOZZLE JET FORCES
. NOZ. PERP. ABOVE WATER, PRESS.=2.0 BAR NOM.

DESCRIPTION                            AVERAGE        RMS        MINIMUM     MAXIMUM
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```
 1 JET FORCE (N)                        0.1164E+02  0.8954E+00  0.9996E+01  0.1385E+02


GROUP NO.  34     TOTAL NO. OF SAMPLES =     1290     29-MAR-1988 23:23:58
T1 =    5.9600 SEC.       T2 =   19.1000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. PERP. ABOVE WATER, PRESS.=4.0 BAR. NOM.

CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                        0.2112E+02  0.5563E+00  0.1944E+02  0.2306E+02


GROUP NO.  35     TOTAL NO. OF SAMPLES =      344     29-MAR-1988 23:25:31
T1 =    0.8200 SEC.       T2 =    5.8000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
  D. NOZ. PERP. ABOVE WATER, PRESS.=4.8 BAR. NOM.

CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                        0.2495E+02  0.2441E+00  0.2418E+02  0.2559E+02


GROUP NO.  36     TOTAL NO. OF SAMPLES =      457     29-MAR-1988 23:51:50
T1 =    4.9600 SEC.       T2 =    9.1000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED. NOZ. HORIZ. 0.5 M. DEPTH, ZERO STATS.

CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM

 1 JET FORCE (N)                       -0.9913E-02  0.9189E-02 -0.2740E-01  0.1346E-01


GROUP NO.  37     TOTAL NO. OF SAMPLES =      389     29-MAR-1988 23:53:54
T1 =    1.5800 SEC.       T2 =    5.2000 SEC.

PROJ. # R4034 NOZZLE JET FORCES
MED NOZ. HORIZ. 0.5 M. DEPTH, PRESS.=4.8 BAR NOM.
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```
DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                         0.2647E+02  0.5311E+00  0.2538E+02  0.2768E+02



UP NO. 38     TOTAL NO. OF SAMPLES =      491      29-MAR-1988 23:57:26
=     0.7400 SEC.      T2 =     4.8200 SEC.

I. ♦ R4034 NOZZLE JET FORCES
. NOZ. HORIZ. 0.5 M. DEPTH, PRESS.=4.0 BAR. NOM.

DESCRIPTION                             AVERAGE        RMS        MINIMUM     MAXIMUM

JET FORCE (N)                         0.2031E+02  0.2643E+00  0.1953E+02  0.2087E+02
```

# APPENDIX F

## DETAILED DATA ON THE SUCTION TESTS

```
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.4499E+01  0.3595E+00 -0.5192E+01 -0.3775E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       0.1101E+01  0.3937E+00  0.4214E+00  0.1929E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       0.1232E+01  0.3184E+00  0.6267E+00  0.1985E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.2205E-02  0.3039E-01 -0.1066E+00  0.8811E-01


GROUP NO.  32     TOTAL NO. OF SAMPLES =     712     28-APR-1988 15:15:40

T1 =     1.0000 SEC.     T2 =   12.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
REPEAT, Vs==5.0 KTS, Vm=0.664 M/S, AHEAD DRAG FORCES


CH DESCRIPTION                        AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.6665E+00  0.2891E-03  0.6657E+00  0.6671E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.1809E-01  0.2941E-01 -0.5827E-01  0.1236E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.1149E-01  0.3437E-01 -0.1314E+00  0.1401E+00
 4 CENTRE THRUST (N)               0.8467E+01  0.1266E+01  0.5335E+01  0.1102E+02
 5 CENTRE TORQUE (Nm)             -0.1555E+00  0.2133E+00 -0.4751E+00  0.2239E+00
 6 SUCT. UPPER BENDING (Nm)        0.2487E+02  0.8681E+00  0.2283E+02  0.2751E+02
 7 SUCT. LOWER BENDING (Nm)        0.2067E+02  0.6801E+00  0.1916E+02  0.2252E+02
 8 SUCT. TORSION (Nm)             -0.7748E+01  0.9671E+00 -0.9429E+01 -0.5756E+01
 9 TOW FORCE (N)                   0.5942E+02  0.1181E+02  0.3689E+02  0.8643E+02
10 PORT SHAFT SPEED (RPS)         -0.4849E-01  0.5006E-03 -0.5005E-01 -0.4675E-01
11 CENTRE SHAFT SPEED (RPS)        0.1680E-01  0.1861E-02  0.1286E-01  0.2302E-01
12 STRBRD. SHAFT SPEED (RPS)      -0.2630E-02  0.5322E-03 -0.4091E-02 -0.1420E-02
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.4400E+01  0.2662E+00 -0.4802E+01 -0.3739E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       0.1150E+01  0.3427E+00  0.5966E+00  0.1964E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       0.1236E+01  0.2744E+00  0.7340E+00  0.1949E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.1250E-01  0.3441E-01 -0.1066E+00  0.1437E+00


GROUP NO.  33     TOTAL NO. OF SAMPLES =     570     28-APR-1988 15:20:11

T1 =     1.0000 SEC.     T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=+10.0 KTS, Vm=1.328 M/S, AHEAD DRAG FORCES


CH DESCRIPTION                        AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.1332E+01  0.1326E-02  0.1330E+01  0.1340E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.4240E-01  0.1531E+00 -0.3441E+00  0.4355E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.8567E-03  0.1584E+00 -0.3486E+00  0.4388E+00
 4 CENTRE THRUST (N)               0.2415E+01  0.5745E+01 -0.9665E+01  0.1580E+02
 5 CENTRE TORQUE (Nm)             -0.4307E+00  0.3033E+00 -0.1326E+01  0.2723E+00
 6 SUCT. UPPER BENDING (Nm)        0.8765E+02  0.1918E+01  0.8348E+02  0.9265E+02
 7 SUCT. LOWER BENDING (Nm)         0.7235E+02  0.1568E+01  0.6918E+02  0.7641E+02
 8 SUCT. TORSION (Nm)              -0.2964E+02  0.9604E+00 -0.3247E+02 -0.2810E+02
 9 TOW FORCE (N)                    0.2325E+03  0.2050E+02  0.1788E+03  0.2924E+03
10 PORT SHAFT SPEED (RPS)           0.1560E+01  0.2095E-01  0.1500E+01  0.1615E+01
11 CENTRE SHAFT SPEED (RPS)         0.2701E+01  0.3079E-01  0.2612E+01  0.2775E+01
12 STRBRD. SHAFT SPEED (RPS)        0.1231E+01  0.4309E-01  0.1152E+01  0.1349E+01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.3473E+01  0.6733E+00 -0.5298E+01 -0.1827E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        0.1672E+01  0.7681E+00 -0.3499E+00  0.3506E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        0.1935E+01  0.7934E+00 -0.1238E+00  0.3879E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.1898E-01  0.1559E+00 -0.5238E+00  0.4497E+00


GROUP NO.  34     TOTAL NO. OF SAMPLES =     1035     28-APR-1988 15:37:21

T1 =    11.0000 SEC.      T2 =    20.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
no run description


CH DESCRIPTION                        AVERAGE       RMS         MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.2222E-04  0.4054E-03 -0.2825E-02  0.1631E-02
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.3370E-01  0.2431E-01 -0.1102E+00  0.7167E-01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.2497E-02  0.2580E-01 -0.7711E-01  0.1130E+00
 4 CENTRE THRUST (N)                0.1644E+02  0.1292E+01  0.1413E+02  0.1894E+02
 5 CENTRE TORQUE (Nm)              -0.4562E+00  0.1094E+00 -0.6308E+00 -0.2779E+00
 6 SUCT. UPPER BENDING (Nm)         0.2411E+00  0.6161E+00 -0.1450E+01  0.1583E+01
 7 SUCT. LOWER BENDING (Nm)         0.5179E+00  0.5076E+00 -0.8541E+00  0.1612E+01
 8 SUCT. TORSION (Nm)              -0.9515E-02  0.2572E+00 -0.6190E+00  0.7936E+00
 9 TOW FORCE (N)                   -0.4108E+03  0.7436E+00 -0.4127E+03 -0.4090E+03
10 PORT SHAFT SPEED (RPS)          -0.4982E-01  0.5029E-03 -0.5170E-01 -0.4840E-01
11 CENTRE SHAFT SPEED (RPS)         0.1673E-01  0.1732E-02  0.1286E-01  0.1963E-01
12 STRBRD. SHAFT SPEED (RPS)       -0.2638E-02  0.5332E-03 -0.4091E-02 -0.5295E-03
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.2162E+01  0.1011E+00 -0.2854E+01 -0.1933E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        0.5406E+00  0.9406E-01  0.1409E+00  0.7369E+00
15 NOZZLE BN [#3 GAUGE] (Nm)        0.3847E+00  0.8943E-01  0.1264E+00  0.6267E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.8724E-01  0.2997E-01 -0.1344E+00  0.1994E+00


GROUP NO.  35     TOTAL NO. OF SAMPLES =      810     28-APR-1988 15:44:38

T1 =     5.0000 SEC.      T2 =    15.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=5 KTS, Vm=0.664 m/s, AHEAD DRAG FORCES


CH DESCRIPTION                        AVERAGE       RMS         MINIMUM     MAXIMUM
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```
  1 CARRIAGE SPEED (M/S)              0.6652E+00  0.1190E-02  0.6615E+00  0.6735E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.3487E-01  0.4728E-01 -0.2532E+00  0.8123E+00
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.8045E-02  0.4782E-01 -0.6983E+00  0.1434E+00
  4 CENTRE THRUST (N)                 0.9627E+01  0.9875E+00  0.7443E+01  0.1158E+02
  5 CENTRE TORQUE (Nm)               -0.5009E+00  0.2226E+00 -0.8696E+00 -0.1291E+00
  6 SUCT. UPPER BENDING (Nm)          0.2687E+02  0.7510E+00  0.2525E+02  0.2886E+02
  7 SUCT. LOWER BENDING (Nm)          0.2218E+02  0.5648E+00  0.2098E+02  0.2357E+02
  8 SUCT. TORSION (Nm)               -0.8983E+01  0.7108E+00 -0.1030E+02 -0.7424E+01
  9 TOW FORCE (N)                     0.6254E+02  0.9547E+01  0.4219E+02  0.8131E+02
 10 PORT SHAFT SPEED (RPS)           -0.5001E-01  0.7408E-03 -0.5912E-01 -0.4757E-01
 11 CENTRE SHAFT SPEED (RPS)          0.1751E-01  0.2690E-02 -0.1934E-01  0.3489E-01
 12 STRBRD. SHAFT SPEED (RPS)        -0.2406E-02  0.7229E-03 -0.7653E-02  0.1251E-02
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.2690E+00  0.3290E+00 -0.4164E+00  0.1142E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.1054E+01  0.4192E+00  0.1141E+00  0.1797E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.1155E+01  0.3401E+00  0.4196E+00  0.2064E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.2077E-01  0.4665E-01 -0.1057E+00  0.5618E+00



GROUP NO.  36     TOTAL NO. OF SAMPLES =    1393     28-APR-1988 15:49:06

T1 =    4.0000 SEC.     T2 =   25.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs 10 Kts, Vm=1.328 m/s, AHEAD DRAG FORCES


CH DESCRIPTION                        AVERAGE       RMS       MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)              0.1332E+01  0.9735E-03  0.1318E+01  0.1335E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.2050E-01  0.1517E+00 -0.4611E+00  0.6304E+00
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.4666E-01  0.1598E+00 -0.5354E+00  0.8222E+00
  4 CENTRE THRUST (N)                 0.5287E+01  0.5895E+01 -0.7397E+01  0.1834E+02
  5 CENTRE TORQUE (Nm)               -0.8048E+00  0.2473E+00 -0.1582E+01 -0.2260E+00
  6 SUCT. UPPER BENDING (Nm)          0.1005E+03  0.3601E+01  0.9175E+02  0.1097E+03
  7 SUCT. LOWER BENDING (Nm)          0.8288E+02  0.1649E+01  0.7844E+02  0.8721E+02
  8 SUCT. TORSION (Nm)               -0.3660E+02  0.1041E+01 -0.3955E+02 -0.3388E+02
  9 TOW FORCE (N)                     0.2406E+03  0.1672E+02  0.1915E+03  0.2917E+03
 10 PORT SHAFT SPEED (RPS)            0.1481E+01  0.2558E-01  0.1413E+01  0.1561E+01
 11 CENTRE SHAFT SPEED (RPS)          0.2599E+01  0.3016E-01  0.2511E+01  0.2710E+01
 12 STRBRD. SHAFT SPEED (RPS)         0.1082E+01  0.2385E-01  0.1037E+01  0.1157E+01
 13 NOZZLE BN [#1 GAUGE] (Nm)        -0.1245E+01  0.2860E+00 -0.2400E+01 -0.3455E+00
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.1946E+01  0.3174E+00  0.6049E+00  0.2849E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.2117E+01  0.3360E+00  0.6698E+00  0.3065E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.5013E-01  0.1557E+00 -0.4673E+00  0.4784E+00



GROUP NO.  37     TOTAL NO. OF SAMPLES =    1074     28-APR-1988 15:55:25

T1 =    1.0000 SEC.     T2 =   15.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=15 Kts, Vm=1.992 m/s, AHEAD DRAG FORCES
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CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                0.1998E+01  0.1124E-02  0.1990E+01  0.2001E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        0.6609E-01  0.2669E+00 -0.5390E+00  0.7084E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.4978E-01  0.2884E+00 -0.7254E+00  0.9309E+00
 4 CENTRE THRUST (N)                   0.1616E+01  0.6706E+01 -0.1285E+02  0.1854E+02
 5 CENTRE TORQUE (Nm)                 -0.6394E+00  0.3237E+00 -0.1631E+01  0.3069E+00
 6 SUCT. UPPER BENDING (Nm)            0.2314E+03  0.9295E+01  0.2075E+03  0.2518E+03
 7 SUCT. LOWER BENDING (Nm)            0.1908E+03  0.3362E+01  0.1794E+03  0.1999E+03
 8 SUCT. TORSION (Nm)                 -0.8529E+02  0.1874E+01 -0.9044E+02 -0.7980E+02
 9 TOW FORCE (N)                       0.5096E+03  0.2025E+02  0.4692E+03  0.5646E+03
10 PORT SHAFT SPEED (RPS)              0.4170E+01  0.2961E-01  0.4082E+01  0.4237E+01
11 CENTRE SHAFT SPEED (RPS)            0.4917E+01  0.4459E-01  0.4803E+01  0.5049E+01
12 STRBRD. SHAFT SPEED (RPS)           0.3535E+01  0.4561E-01  0.3449E+01  0.3633E+01
13 NOZZLE BN [#1 GAUGE] (Nm)           0.1514E+01  0.8635E+00 -0.5581E+00  0.3515E+01
14 NOZZLE BN [#2 GAUGE] (Nm)           0.2008E+01  0.9572E+00 -0.4117E+00  0.4216E+01
15 NOZZLE BN [#3 GAUGE] (Nm)           0.2342E+01  0.1040E+01 -0.3667E+00  0.4709E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)        0.7931E-01  0.2811E+00 -0.5507E+00  0.7843E+00



GROUP NO.  38     TOTAL NO. OF SAMPLES =     4557     28-APR-1988 16:05:03

T1 =    10.0000 SEC.     T2 =    11.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD BOLLARD, CENT. SHAFT 100% POWER, WING SHAFTS VARIABLE


CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.5096E-03  0.7642E-03 -0.3716E-02  0.1631E-02
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.1035E+01  0.6745E+00 -0.2202E+01  0.6700E-02
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.3229E+00  0.6868E+00 -0.1350E+01  0.8494E+00
 4 CENTRE THRUST (N)                   0.9626E+02  0.5679E+01  0.8308E+02  0.1085E+03
 5 CENTRE TORQUE (Nm)                  0.5407E+01  0.2958E+00  0.4670E+01  0.5878E+01
 6 SUCT. UPPER BENDING (Nm)            0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)            0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)                 -0.4134E+03  0.0000E+00 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                      -0.1429E+03  0.2501E+01 -0.1473E+03 -0.1395E+03
10 PORT SHAFT SPEED (RPS)              0.2617E+00  0.2175E-02  0.2469E+00  0.2634E+00
11 CENTRE SHAFT SPEED (RPS)            0.6992E+01  0.1514E-01  0.6970E+01  0.7023E+01
12 STRBRD. SHAFT SPEED (RPS)           0.1670E+00  0.4460E-02  0.1366E+00  0.1695E+00
13 NOZZLE BN [#1 GAUGE] (Nm)          -0.1438E+02  0.7970E+00 -0.1596E+02 -0.1299E+02
14 NOZZLE BN [#2 GAUGE] (Nm)          -0.2077E+02  0.8397E+00 -0.2243E+02 -0.1910E+02
15 NOZZLE BN [#3 GAUGE] (Nm)          -0.2321E+02  0.8161E+00 -0.2492E+02 -0.2174E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)       -0.2933E+00  0.6841E+00 -0.1246E+01  0.7565E+00
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# APPENDIX G

## DETAILED DATA ON THE OVERLOAD TESTS

TEST # 193

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GROUP NO.   6     TOTAL NO. OF SAMPLES =     780     27-APR-1988 10:49:27

T1 =    11.0000 SEC.     T2 =    15.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ZERO SPEED CHECK

CH DESCRIPTION                              AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                -0.1895E-02  0.1967E-02 -0.6532E-02  0.2109E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        -0.9292E-02  0.7445E-01 -0.8626E+00  0.3848E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)         0.4006E-02  0.5821E-01 -0.1957E+00  0.5918E+00
 4 CENTRE THRUST (N)                   -0.2068E+00  0.1257E+01 -0.2504E+01  0.2191E+01
 5 CENTRE TORQUE (Nm)                   0.5750E+00  0.1318E+00  0.3057E+00  0.8697E+00
 6 TOW FORCE (N)                       -0.4622E+01  0.1640E+01 -0.7575E+01 -0.1816E+01
 7 PORT SHAFT SPEED (RPS)              -0.5020E-01  0.1289E-02 -0.6324E-01 -0.4675E-01
 8 CENTRE SHAFT SPEED (RPS)             0.3182E-01  0.3441E-02 -0.6987E-03  0.4675E-01
 9 STRBRD. SHAFT SPEED (RPS)           -0.2266E-02  0.1112E-02 -0.1300E-01  0.1251E-02
10 NOZZLE BN [#1 GAUGE] (Nm)             0.5737E-01  0.2116E+00 -0.7153E+00  0.2508E+01
11 NOZZLE BN [#2 GAUGE] (Nm)            0.5705E-01  0.1430E+00 -0.2018E+00  0.1551E+01
12 NOZZLE BN [#3 GAUGE] (Nm)            0.2712E-01  0.2576E+00 -0.1668E+01  0.1870E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)        -0.5488E-02  0.5212E-01 -0.5189E+00  0.2877E+00



GROUP NO.   7     TOTAL NO. OF SAMPLES =    1744     27-APR-1988 10:53:22

T1 =     5.0000 SEC.     T2 =    30.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD, 100% POWER -- ALL SHAFTS

CH DESCRIPTION                              AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                -0.2081E-02  0.2464E-02 -0.3326E-01  0.3401E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        -0.1124E+01  0.6810E+00 -0.3280E+01  0.1034E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)        -0.4132E+00  0.7089E+00 -0.2667E+01  0.1433E+01
 4 CENTRE THRUST (N)                    0.6089E+02  0.4960E+01  0.4719E+02  0.7512E+02
 5 CENTRE TORQUE (Nm)                   0.4156E+01  0.4503E+00  0.3057E+01  0.5240E+01
 6 TOW FORCE (N)                       -0.4465E+03  0.3687E+01 -0.4568E+03 -0.4387E+03
 7 PORT SHAFT SPEED (RPS)               0.8564E+01  0.3721E-02  0.8532E+01  0.8581E+01
 8 CENTRE SHAFT SPEED (RPS)             0.6367E+01  0.1619E-01  0.6286E+01  0.6428E+01
 9 STRBRD. SHAFT SPEED (RPS)            0.8392E+01  0.1032E-01  0.8348E+01  0.8416E+01
10 NOZZLE BN [#1 GAUGE] (Nm)             0.1783E+02  0.1086E+01  0.1462E+02  0.2156E+02
11 NOZZLE BN [#2 GAUGE] (Nm)            0.1976E+02  0.1174E+01  0.1638E+02  0.2483E+02
12 NOZZLE BN [#3 GAUGE] (Nm)            0.2159E+02  0.1263E+01  0.1778E+02  0.2525E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)        -0.4063E+00  0.6886E+00 -0.3106E+01  0.1706E+01
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GROUP NO.   8     TOTAL NO. OF SAMPLES =     2295      27-APR-1988 11:18:37

T1 =     5.0000 SEC.      T2 =    37.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD @ 100% POWER -- ALL SHAFTS


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.2029E-02  0.2385E-02 -0.3059E-01  0.2510E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1613E+01  0.7379E+00 -0.3981E+01  0.2074E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.7606E+00  0.7651E+00 -0.3997E+01  0.1352E+01
 4 CENTRE THRUST (N)                  0.8410E+02  0.5683E+01  0.7003E+02  0.1003E+03
 5 CENTRE TORQUE (Nm)                 0.5353E+01  0.5230E+00  0.4022E+01  0.6590E+01
 6 TOW FORCE (N)                     -0.4806E+03  0.2857E+01 -0.4901E+03 -0.4705E+03
 7 PORT SHAFT SPEED (RPS)             0.8666E+01  0.3473E-02  0.8643E+01  0.8692E+01
 8 CENTRE SHAFT SPEED (RPS)           0.7097E+01  0.1903E-01  0.7008E+01  0.7165E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.8436E+01  0.1045E-01  0.8398E+01  0.8484E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.2226E+02  0.1199E+01  0.1813E+02  0.2751E+02
11 NOZZLE BN [#2 GAUGE] (Nm)          0.2457E+02  0.1298E+01  0.2080E+02  0.2893E+02
12 NOZZLE BN [#3 GAUGE] (Nm)          0.2684E+02  0.1372E+01  0.2289E+02  0.3150E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)      -0.7169E+00  0.7430E+00 -0.2967E+01  0.2068E+01




GROUP NO.   9     TOTAL NO. OF SAMPLES =     1013      27-APR-1988 11:24:13

T1 =     6.0000 SEC.      T2 =    20.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD @ 100% POWER -- CENTER ONLY


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.2015E-02  0.1636E-02 -0.3148E-01  0.1485E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1156E+01  0.5761E+00 -0.2188E+01  0.4368E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.4126E+00  0.6077E+00 -0.1418E+01  0.9176E+00
 4 CENTRE THRUST (N)                  0.8377E+02  0.4536E+01  0.7265E+02  0.9402E+02
 5 CENTRE TORQUE (Nm)                 0.5480E+01  0.5415E+00  0.4192E+01  0.6638E+01
 6 TOW FORCE (N)                     -0.1614E+03  0.3548E+01 -0.1731E+03 -0.1501E+03
 7 PORT SHAFT SPEED (RPS)            -0.5156E-01  0.8993E-03 -0.5995E-01 -0.4262E-01
 8 CENTRE SHAFT SPEED (RPS)           0.7107E+01  0.1636E-01  0.7064E+01  0.7152E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.1890E-02  0.2553E-02 -0.3348E-01  0.3242E-01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.2011E+02  0.7645E+00  0.1738E+02  0.2167E+02
11 NOZZLE BN [#2 GAUGE] (Nm)          0.2250E+02  0.8042E+00  0.2090E+02  0.2525E+02
12 NOZZLE BN [#3 GAUGE] (Nm)          0.2483E+02  0.7939E+00  0.2328E+02  0.2696E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)      -0.2787E+00  0.5977E+00 -0.1687E+01  0.7884E+00




GROUP NO.  10     TOTAL NO. OF SAMPLES =     1665      27-APR-1988 11:29:27
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T1 =    3.0000 SEC.     T2 =    33.2800 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD @ 75 % POWER -- ALL SHAFTS

CH DESCRIPTION                           AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1939E-02  0.2583E-02 -0.4218E-01  0.3134E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.1101E+01  0.5108E+00 -0.2838E+01  0.1606E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.4981E+00  0.5170E+00 -0.2314E+01  0.8904E+00
 4 CENTRE THRUST (N)                   0.6049E+02  0.4177E+01  0.4974E+02  0.7440E+02
 5 CENTRE TORQUE (Nm)                  0.3536E+01  0.4521E+00  0.2468E+01  0.4458E+01
 6 TOW FORCE (N)                      -0.3323E+03  0.2618E+01 -0.3409E+03 -0.3231E+03
 7 PORT SHAFT SPEED (RPS)              0.7217E+01  0.4994E-02  0.7175E+01  0.7239E+01
 8 CENTRE SHAFT SPEED (RPS)            0.5771E+01  0.1502E-01  0.5683E+01  0.5835E+01
 9 STRBRD. SHAFT SPEED (RPS)           0.7045E+01  0.1375E-01  0.6988E+01  0.7082E+01
10 NOZZLE BN [#1 GAUGE] (Nm)           0.1496E+02  0.1180E+01  0.1037E+02  0.1866E+02
11 NOZZLE BN [#2 GAUGE] (Nm)           0.1663E+02  0.1313E+01  0.1270E+02  0.2090E+02
12 NOZZLE BN [#3 GAUGE] (Nm)           0.1823E+02  0.1414E+01  0.1452E+02  0.2221E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)       -0.4339E+00  0.5292E+00 -0.2132E+01  0.2012E+01



GROUP NO.  11     TOTAL NO. OF SAMPLES =     1535     27-APR-1988 11:32:58

T1 =    3.0000 SEC.     T2 =    30.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD @ 50 % POWER -- ALL SHAFTS

CH DESCRIPTION                           AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.2227E-02  0.2752E-02 -0.3638E-01  0.2510E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.6989E+00  0.3480E+00 -0.2786E+01  0.1034E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.2961E+00  0.3562E+00 -0.1933E+01  0.1705E+01
 4 CENTRE THRUST (N)                   0.4656E+02  0.3616E+01  0.3808E+02  0.5523E+02
 5 CENTRE TORQUE (Nm)                  0.2591E+01  0.4106E+00  0.1614E+01  0.3548E+01
 6 TOW FORCE (N)                      -0.1916E+03  0.1751E+01 -0.2004E+03 -0.1811E+03
 7 PORT SHAFT SPEED (RPS)              0.5450E+01  0.3087E-02  0.5425E+01  0.5483E+01
 8 CENTRE SHAFT SPEED (RPS)            0.4808E+01  0.1278E-01  0.4744E+01  0.4868E+01
 9 STRBRD. SHAFT SPEED (RPS)           0.5213E+01  0.7855E-02  0.5181E+01  0.5243E+01
10 NOZZLE BN [#1 GAUGE] (Nm)           0.9921E+01  0.6201E+00  0.7254E+01  0.1267E+02
11 NOZZLE BN [#2 GAUGE] (Nm)           0.1095E+02  0.6615E+00  0.7721E+01  0.1354E+02
12 NOZZLE BN [#3 GAUGE] (Nm)           0.1199E+02  0.6924E+00  0.9054E+01  0.1427E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)       -0.2190E+00  0.3512E+00 -0.3384E+01  0.2569E+01



GROUP NO.  12     TOTAL NO. OF SAMPLES =     1690     27-APR-1988 11:36:18

T1 =    3.0000 SEC.     T2 =    30.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION
BOLLARD @ 25% POWER -- ALL SHAFTS

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)              -0.1932E-02  0.2577E-02 -0.3237E-01  0.3357E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.4314E+00  0.2385E+00 -0.1902E+01  0.1502E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.2071E+00  0.2369E+00 -0.2449E+01  0.1977E+01
 4 CENTRE THRUST (N)                  0.3166E+02  0.3747E+01  0.2212E+02  0.4031E+02
 5 CENTRE TORQUE (Nm)                 0.1547E+01  0.3856E+00  0.6725E+00  0.2434E+01
 6 TOW FORCE (N)                     -0.1078E+03  0.1390E+01 -0.1170E+03 -0.9700E+02
 7 PORT SHAFT SPEED (RPS)             0.4123E+01  0.2348E-02  0.4094E+01  0.4148E+01
 8 CENTRE SHAFT SPEED (RPS)           0.3526E+01  0.1112E-01  0.3434E+01  0.3581E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.4092E+01  0.4357E-02  0.4057E+01  0.4137E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.5671E+01  0.4138E+00  0.1693E+01  0.8493E+01
11 NOZZLE BN [#2 GAUGE] (Nm)          0.6205E+01  0.4122E+00  0.4215E+01  0.9404E+01
12 NOZZLE BN [#3 GAUGE] (Nm)          0.6709E+01  0.4078E+00  0.4515E+01  0.9233E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      -0.1195E+00  0.2217E+00 -0.1715E+01  0.1539E+01



GROUP NO.  13     TOTAL NO. OF SAMPLES =     733     27-APR-1988 11:41:41

T1 =     5.0000 SEC.     T2 =    14.6400 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ZERO SPEED STATS CHECK

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)              -0.2052E-02  0.1094E-02 -0.1277E-01  0.1084E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.9287E-02  0.7768E-01 -0.9406E+00  0.6966E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.1044E-01  0.1337E+00 -0.1119E+01  0.1949E+01
 4 CENTRE THRUST (N)                  0.1235E+02  0.2649E+01  0.6965E+01  0.1854E+02
 5 CENTRE TORQUE (Nm)                 0.3844E+00  0.3713E+00 -0.5040E+00  0.1019E+01
 6 TOW FORCE (N)                     -0.2818E+01  0.7828E+00 -0.7140E+01  0.2530E+01
 7 PORT SHAFT SPEED (RPS)            -0.5177E-01  0.1423E-02 -0.5747E-01 -0.3190E-01
 8 CENTRE SHAFT SPEED (RPS)           0.7117E-01  0.3673E-02  0.3658E-01  0.1213E+00
 9 STRBRD. SHAFT SPEED (RPS)         -0.1615E-02  0.2275E-02 -0.1478E-01  0.2084E-01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.3092E+00  0.1499E+00 -0.1176E+01  0.6306E+00
11 NOZZLE BN [#2 GAUGE] (Nm)          0.1303E+00  0.1470E+00 -0.9380E+00  0.1060E+01
12 NOZZLE BN [#3 GAUGE] (Nm)          0.2179E-01  0.1780E+00 -0.1275E+01  0.1477E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.1373E+00  0.9018E-01 -0.6301E+00  0.1289E+01



GROUP NO.  14     TOTAL NO. OF SAMPLES =    6151     27-APR-1988 12:03:20

T1 =     2.0000 SEC.     T2 =    10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
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OVERLOAD, Vs= 5Kts, Vm = 0.644 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION
                                      AVERAGE        RMS         MINIMUM       MAXIMUM

 1 CARRIAGE SPEED (M/S)             -0.6649E+00   0.3493E-02  -0.6949E+00  -0.6468E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.6543E-01   0.2367E+00  -0.2240E+01   0.2698E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.3416E-01   0.1634E+00  -0.1010E+01   0.9991E+00
 4 CENTRE THRUST (N)                 0.2243E+02   0.1914E+01   0.1679E+02   0.2734E+02
 5 CENTRE TORQUE (Nm)                0.1215E+01   0.6408E+00  -0.2480E+00   0.2714E+01
 6 TOW FORCE (N)                    -0.3174E+02   0.1425E+02  -0.6071E+02  -0.2950E+00
 7 PORT SHAFT SPEED (RPS)            0.4133E+01   0.3506E-02   0.4108E+01   0.4150E+01
 8 CENTRE SHAFT SPEED (RPS)          0.3311E+01   0.1239E-01   0.3234E+01   0.3348E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.4084E+01   0.5103E-02   0.4054E+01   0.4105E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.2052E+01   0.8171E+00  -0.1317E+01   0.4704E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         0.2039E+01   0.1011E+01   0.7867E-01   0.4215E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         0.2123E+01   0.8295E+00   0.1165E-01   0.5373E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.7091E-01   0.1810E+00  -0.1214E+01   0.1067E+01


GROUP NO.  14     TOTAL NO. OF SAMPLES =    6151     27-APR-1988 12:03:20

T1 =    30.0000 SEC.      T2 =    50.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs= 5Kts, Vm = 0.644 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION
                                      AVERAGE        RMS         MINIMUM       MAXIMUM

 1 CARRIAGE SPEED (M/S)             -0.6648E+00   0.2557E-02  -0.6869E+00  -0.6441E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.3081E+00   0.3197E+00  -0.2084E+01   0.1892E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.6572E-01   0.3199E+00  -0.2667E+01   0.1569E+01
 4 CENTRE THRUST (N)                 0.3833E+02   0.2404E+01   0.3195E+02   0.4413E+02
 5 CENTRE TORQUE (Nm)                0.2277E+01   0.5861E+00   0.1043E+01   0.3600E+01
 6 TOW FORCE (N)                    -0.9929E+02   0.6476E+01  -0.1167E+03  -0.8201E+02
 7 PORT SHAFT SPEED (RPS)            0.5444E+01   0.4429E-02   0.5403E+01   0.5476E+01
 8 CENTRE SHAFT SPEED (RPS)          0.4827E+01   0.3136E-01   0.4664E+01   0.4886E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.5410E+01   0.1129E-01   0.5370E+01   0.5452E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.5582E+01   0.6944E+00   0.3039E+01   0.8741E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         0.5923E+01   0.8423E+00   0.1271E+01   0.8527E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         0.6338E+01   0.7354E+00   0.3836E+01   0.8411E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.5894E-01   0.3398E+00  -0.1520E+01   0.2902E+01


GROUP NO.  14     TOTAL NO. OF SAMPLES =    6151     27-APR-1988 12:03:20

T1 =    72.0000 SEC.      T2 =    90.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs= 5Kts, Vm = 0.644 m/s, VARIABLE SHAFT SPEED
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CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.6648E+00  0.2498E-02 -0.6940E+00 -0.6454E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.4863E+00  0.4138E+00 -0.2890E+01  0.1970E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1246E+00  0.4101E+00 -0.2476E+01  0.1406E+01
 4 CENTRE THRUST (N)                 0.5087E+02  0.2826E+01  0.4401E+02  0.5960E+02
 5 CENTRE TORQUE (Nm)                0.3234E+01  0.6139E+00  0.1866E+01  0.4531E+01
 6 TOW FORCE (N)                    -0.1945E+03  0.5186E+01 -0.2055E+03 -0.1790E+03
 7 PORT SHAFT SPEED (RPS)            0.7117E+01  0.4700E-02  0.7088E+01  0.7135E+01
 8 CENTRE SHAFT SPEED (RPS)          0.5690E+01  0.1585E-01  0.5623E+01  0.5744E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.6960E+01  0.1234E-01  0.6929E+01  0.6994E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.8778E+01  0.6546E+00  0.5872E+01  0.1189E+02
11 NOZZLE BN [#2 GAUGE] (Nm)         0.9487E+01  0.6904E+00  0.6249E+01  0.1312E+02
12 NOZZLE BN [#3 GAUGE] (Nm)         0.1025E+02  0.7131E+00  0.8197E+01  0.1395E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)     -0.3196E-01  0.4076E+00 -0.2076E+01  0.1929E+01



GROUP NO.  14     TOTAL NO. OF SAMPLES =     6151     27-APR-1988 12:03:20

T1 =  103.0000 SEC.      T2 =  120.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs= 5Kts, Vm = 0.644 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.6648E+00  0.2895E-02 -0.6967E+00 -0.6370E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.8224E+00  0.5750E+00 -0.2240E+01  0.1112E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2307E+00  0.6222E+00 -0.2721E+01  0.2683E+01
 4 CENTRE THRUST (N)                 0.7436E+02  0.3452E+01  0.6617E+02  0.8336E+02
 5 CENTRE TORQUE (Nm)                0.4525E+01  0.6881E+00  0.2977E+01  0.6105E+01
 6 TOW FORCE (N)                    -0.3495E+03  0.5574E+01 -0.3634E+03 -0.3338E+03
 7 PORT SHAFT SPEED (RPS)            0.8960E+01  0.4031E-02  0.8922E+01  0.8991E+01
 8 CENTRE SHAFT SPEED (RPS)          0.6979E+01  0.1892E-01  0.6925E+01  0.7043E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.8661E+01  0.9595E-02  0.8613E+01  0.8693E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.1449E+02  0.8689E+00  0.1242E+02  0.1834E+02
11 NOZZLE BN [#2 GAUGE] (Nm)         0.1588E+02  0.9203E+00  0.1259E+02  0.1866E+02
12 NOZZLE BN [#3 GAUGE] (Nm)         0.1730E+02  0.9431E+00  0.1438E+02  0.1971E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1262E+00  0.5983E+00 -0.1743E+01  0.1623E+01



GROUP NO.  15     TOTAL NO. OF SAMPLES =     4018     27-APR-1988 12:15:17

T1 =   14.0000 SEC.      T2 =   20.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM
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```
 1 CARRIAGE SPEED (M/S)              -0.1330E+01  0.2904E-02 -0.1341E+01 -0.1324E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.7449E-01  0.1964E+00 -0.6027E+00  0.1294E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.1029E+00  0.1910E+00 -0.6844E+00  0.1325E+01
 4 CENTRE THRUST (N)                  0.1837E+02  0.1155E+02 -0.3022E+01  0.4468E+02
 5 CENTRE TORQUE (Nm)                -0.2276E+00  0.5805E+00 -0.1435E+01  0.1153E+01
 6 TOW FORCE (N)                      0.3231E+02  0.3072E+01  0.1350E+02  0.3295E+02
 7 PORT SHAFT SPEED (RPS)             0.4163E+01  0.4154E-02  0.4158E+01  0.4186E+01
 8 CENTRE SHAFT SPEED (RPS)           0.3411E+01  0.1019E-01  0.3383E+01  0.3463E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.3831E+01  0.3543E-02  0.3806E+01  0.3844E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.5173E+00  0.7966E+00 -0.2132E+01  0.9848E+00
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.5082E+00  0.1051E+01 -0.2551E+01  0.2673E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.6768E+00  0.8540E+00 -0.3098E+01  0.2156E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.1780E+00  0.2278E+00 -0.2049E+01  0.1484E+01



GROUP NO.  15     TOTAL NO. OF SAMPLES =     4018     27-APR-1988 12:15:17

T1 =   26.0000 SEC.       T2 =   36.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1330E+01  0.3117E-02 -0.1368E+01 -0.1316E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1756E+00  0.2569E+00 -0.1434E+01  0.7226E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.6271E-01  0.2681E+00 -0.1689E+01  0.9719E+00
 4 CENTRE THRUST (N)                  0.2206E+02  0.3815E+01  0.1333E+02  0.3187E+02
 5 CENTRE TORQUE (Nm)                 0.1002E+01  0.5371E+00 -0.1961E+00  0.2254E+01
 6 TOW FORCE (N)                      0.3090E+02  0.4426E+01  0.1437E+02  0.3295E+02
 7 PORT SHAFT SPEED (RPS)             0.5523E+01  0.3416E-02  0.5511E+01  0.5544E+01
 8 CENTRE SHAFT SPEED (RPS)           0.4765E+01  0.1508E-01  0.4707E+01  0.4803E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.5425E+01  0.9045E-02  0.5405E+01  0.5473E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.1480E+01  0.7271E+00 -0.5028E+00  0.3783E+01
11 NOZZLE BN [#2 GAUGE] (Nm)          0.1653E+01  0.8591E+00 -0.6575E+00  0.4180E+01
12 NOZZLE BN [#3 GAUGE] (Nm)          0.1905E+01  0.8109E+00 -0.4530E+00  0.3979E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.5279E-01  0.2938E+00 -0.1910E+01  0.1539E+01



GROUP NO.  15     TOTAL NO. OF SAMPLES =     4018     27-APR-1988 12:15:17

T1 =   45.0000 SEC.       T2 =   54.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM
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```
 1 CARRIAGE SPEED (M/S)            -0.1330E+01  0.2251E-02 -0.1349E+01 -0.1310E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.3001E+00  0.3394E+00 -0.1616E+01  0.1476E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.9318E-01  0.3624E+00 -0.1390E+01  0.1705E+01
 4 CENTRE THRUST (N)                 0.3482E+02  0.3976E+01  0.2455E+02  0.4512E+02
 5 CENTRE TORQUE (Nm)                0.2130E+01  0.5031E+00  0.9770E+00  0.3247E+01
 6 TOW FORCE (N)                    -0.4427E+02  0.7051E+01 -0.6082E+02 -0.2594E+02
 7 PORT SHAFT SPEED (RPS)            0.7158E+01  0.3788E-02  0.7133E+01  0.7187E+01
 8 CENTRE SHAFT SPEED (RPS)          0.5543E+01  0.1659E-01  0.5500E+01  0.5584E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.7123E+01  0.8819E-02  0.7080E+01  0.7139E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.3771E+01  0.1383E+01  0.8785E+00  0.6545E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         0.4160E+01  0.1508E+01  0.8850E+00  0.7230E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         0.4537E+01  0.1647E+01  0.8337E+00  0.8125E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.2982E-01  0.3412E+00 -0.1325E+01  0.1567E+01


GROUP NO.  15     TOTAL NO. OF SAMPLES =    4018     27-APR-1988 12:15:17

T1 =   61.0000 SEC.      T2 =   74.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VARIABLE SHAFT SPEED

CH DESCRIPTION                       AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1330E+01  0.1957E-02 -0.1349E+01 -0.1315E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.6151E+00  0.5786E+00 -0.2864E+01  0.1112E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.2350E+00  0.6119E+00 -0.3698E+01  0.1461E+01
 4 CENTRE THRUST (N)                 0.6049E+02  0.4415E+01  0.4743E+02  0.7194E+02
 5 CENTRE TORQUE (Nm)                0.3817E+01  0.6903E+00  0.2372E+01  0.5316E+01
 6 TOW FORCE (N)                    -0.1800E+03  0.8722E+01 -0.1999E+03 -0.1614E+03
 7 PORT SHAFT SPEED (RPS)            0.9045E+01  0.3485E-02  0.9019E+01  0.9069E+01
 8 CENTRE SHAFT SPEED (RPS)          0.6980E+01  0.2134E-01  0.6909E+01  0.7040E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.8699E+01  0.8448E-02  0.8677E+01  0.8739E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         0.8434E+01  0.8802E+00  0.5802E+01  0.1161E+02
11 NOZZLE BN [#2 GAUGE] (Nm)         0.9321E+01  0.9474E+00  0.6143E+01  0.1172E+02
12 NOZZLE BN [#3 GAUGE] (Nm)         0.1018E+02  0.9434E+00  0.7660E+01  0.1234E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)    -0.8162E-01  0.6067E+00 -0.1937E+01  0.1845E+01


GROUP NO.  16     TOTAL NO. OF SAMPLES =    2995     27-APR-1988 12:28:39

T1 =    1.0000 SEC.      T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VAR. SHAFT SPEED [REPEAT]

CH DESCRIPTION                       AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1330E+01  0.3670E-02 -0.1361E+01 -0.1312E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.8734E-01  0.2006E+00 -0.1200E+01  0.1164E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)   0.1320E+00  0.1980E+00 -0.8473E+00  0.1379E+01
 4 CENTRE THRUST (N)              0.1845E+02  0.9771E+01 -0.4175E+01  0.4436E+02
 5 CENTRE TORQUE (Nm)            -0.5809E+00  0.5657E+00 -0.1937E+01  0.8455E+00
 6 TOW FORCE (N)                  0.1079E+03  0.6323E+02 -0.2083E+02  0.3358E+03
 7 PORT SHAFT SPEED (RPS)         0.4193E+01  0.3100E-02  0.4158E+01  0.4209E+01
 8 CENTRE SHAFT SPEED (RPS)       0.3437E+01  0.9177E-02  0.3366E+01  0.3495E+01
 9 STRBRD. SHAFT SPEED (RPS)      0.3977E+01  0.3048E-02  0.3961E+01  0.3999E+01
10 NOZZLE BN [#1 GAUGE] (Nm)      0.2384E-01  0.8166E+00 -0.1884E+01  0.2012E+01
11 NOZZLE BN [#2 GAUGE] (Nm)     -0.2246E+00  0.1068E+01 -0.3147E+01  0.2533E+01
12 NOZZLE BN [#3 GAUGE] (Nm)     -0.4532E+00  0.8405E+00 -0.2455E+01  0.1513E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)   0.2120E+00  0.2192E+00 -0.8526E+00  0.1845E+01


GROUP NO.  16     TOTAL NO. OF SAMPLES =     2995     27-APR-1988 12:28:39

T1 =   17.0000 SEC.      T2 =    23.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VAR. SHAFT SPEED [REPEAT]

CH DESCRIPTION                     AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)          -0.1330E+01  0.3319E-02 -0.1345E+01 -0.1306E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)  -0.1680E+00  0.2679E+00 -0.1278E+01  0.1242E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)  -0.6611E-01  0.2699E+00 -0.1119E+01  0.1135E+01
 4 CENTRE THRUST (N)              0.2397E+02  0.3928E+01  0.1508E+02  0.3394E+02
 5 CENTRE TORQUE (Nm)             0.1147E+01  0.5232E+00 -0.1061E+00  0.2372E+01
 6 TOW FORCE (N)                  0.4398E+02  0.1614E+02  0.2204E+01  0.6523E+02
 7 PORT SHAFT SPEED (RPS)         0.5658E+01  0.3228E-02  0.5643E+01  0.5680E+01
 8 CENTRE SHAFT SPEED (RPS)       0.4757E+01  0.1509E-01  0.4681E+01  0.4805E+01
 9 STRBRD. SHAFT SPEED (RPS)      0.5182E+01  0.5622E-02  0.5161E+01  0.5203E+01
10 NOZZLE BN [#1 GAUGE] (Nm)      0.2247E+01  0.6834E+00  0.4889E+00  0.4243E+01
11 NOZZLE BN [#2 GAUGE] (Nm)      0.2270E+01  0.8455E+00  0.2540E+00  0.4671E+01
12 NOZZLE BN [#3 GAUGE] (Nm)      0.2284E+01  0.7470E+00  0.3691E+00  0.5873E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)   0.5330E-01  0.2688E+00 -0.1020E+01  0.1122E+01


GROUP NO.  16     TOTAL NO. OF SAMPLES =     2995     27-APR-1988 12:28:39

T1 =   29.0000 SEC.      T2 =    33.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VAR. SHAFT SPEED [REPEAT]

CH DESCRIPTION                     AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)          -0.1330E+01  0.1789E-02 -0.1344E+01 -0.1323E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)  -0.3106E+00  0.3292E+00 -0.1252E+01  0.4368E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)  -0.9701E-01  0.3399E+00 -0.7115E+00  0.6189E+00
 4 CENTRE THRUST (N)              0.3777E+02  0.4029E+01  0.2869E+02  0.4934E+02
 5 CENTRE TORQUE (Nm)                 0.2175E+01  0.5466E+00  0.1005E+01  0.3354E+01
 6 TOW FORCE (N)                     -0.4437E+02  0.1246E+02 -0.6821E+02 -0.2626E+02
 7 PORT SHAFT SPEED (RPS)             0.7146E+01  0.2870E-02  0.7136E+01  0.7154E+01
 8 CENTRE SHAFT SPEED (RPS)           0.5712E+01  0.1844E-01  0.5657E+01  0.5810E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.7251E+01  0.8961E-02  0.7224E+01  0.7279E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.4447E+01  0.8684E+00  0.2649E+01  0.6970E+01
11 NOZZLE BN [#2 GAUGE] (Nm)          0.4707E+01  0.8917E+00  0.2673E+01  0.7055E+01
12 NOZZLE BN [#3 GAUGE] (Nm)          0.4933E+01  0.9167E+00  0.2942E+01  0.7053E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.3212E-01  0.3476E+00 -0.6579E+00  0.1122E+01



GROUP NO.  16     TOTAL NO. OF SAMPLES =     2995     27-APR-1988 12:28:39

T1 =    41.0000 SEC.     T2 =    55.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 10 Kts, Vm = 1.328 m/s, VAR. SHAFT SPEED [REPEAT]

CH DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1330E+01  0.1817E-02 -0.1341E+01 -0.1310E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.6165E+00  0.5846E+00 -0.2396E+01  0.1268E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.2628E+00  0.6078E+00 -0.1608E+01  0.2683E+01
 4 CENTRE THRUST (N)                  0.6140E+02  0.4355E+01  0.4719E+02  0.7313E+02
 5 CENTRE TORQUE (Nm)                 0.3686E+01  0.6758E+00  0.2209E+01  0.5299E+01
 6 TOW FORCE (N)                     -0.1620E+03  0.1246E+02 -0.1927E+03 -0.1325E+03
 7 PORT SHAFT SPEED (RPS)             0.8609E+01  0.3463E-02  0.8571E+01  0.8632E+01
 8 CENTRE SHAFT SPEED (RPS)           0.6986E+01  0.2136E-01  0.6897E+01  0.7067E+01
 9 STRBRD. SHAFT SPEED (RPS)          0.8615E+01  0.8101E-02  0.8582E+01  0.8637E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.8839E+01  0.8537E+00  0.6475E+01  0.1090E+02
11 NOZZLE BN [#2 GAUGE] (Nm)          0.9465E+01  0.9333E+00  0.7406E+01  0.1175E+02
12 NOZZLE BN [#3 GAUGE] (Nm)          0.1022E+02  0.9533E+00  0.7517E+01  0.1270E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)      -0.7274E-01  0.5957E+00 -0.1965E+01  0.1484E+01



GROUP NO.  17     TOTAL NO. OF SAMPLES =     2045     27-APR-1988 12:38:22

T1 =     0.5000 SEC.     T2 =     7.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 15 Kts, Vm = 1.992 m/s, VAR. SHAFT SPEED

CH DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)               0.1886E+01  0.1578E+00  0.1467E+01  0.2007E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.2933E+00  0.2817E+00 -0.1278E+01  0.1866E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.2420E+00  0.2782E+00 -0.1065E+01  0.1569E+01
 4 CENTRE THRUST (N)                  0.2368E+02  0.1481E+02 -0.1611E+02  0.5586E+02
 5 CENTRE TORQUE (Nm)                -0.1335E+01  0.7841E+00 -0.3006E+01  0.8213E+00
 6 TOW FORCE (N)                      0.2572E+03  0.3528E+03 -0.8711E+02  0.1207E+04
 7 PORT SHAFT SPEED (RPS)            0.4137E+01  0.4662E-02  0.4107E+01  0.4154E+01
 8 CENTRE SHAFT SPEED (RPS)          0.3573E+01  0.1383E-01  0.3519E+01  0.3614E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.4068E+01  0.3820E-02  0.4040E+01  0.4078E+01
10 NOZZLE BN [#1 GAUGE] (Nm)        -0.3150E+01  0.1193E+01 -0.5851E+01  0.9931E-01
11 NOZZLE BN [#2 GAUGE] (Nm)        -0.3496E+01  0.1514E+01 -0.6968E+01  0.5344E+00
12 NOZZLE BN [#3 GAUGE] (Nm)        -0.3957E+01  0.1237E+01 -0.6922E+01 -0.2743E+00
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.3346E+00  0.2756E+00 -0.7692E+00  0.1901E+01


GROUP NO.  17     TOTAL NO. OF SAMPLES =     2045     27-APR-1988 12:38:22

T1 =     8.0000 SEC.      T2 =    11.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 15 Kts, Vm = 1.992 m/s, VAR. SHAFT SPEED

CH DESCRIPTION                        AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              0.1995E+01  0.3602E-02  0.1972E+01  0.2005E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.3285E+00  0.2898E+00 -0.9406E+00  0.9825E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.2956E+00  0.3326E+00 -0.7115E+00  0.1433E+01
 4 CENTRE THRUST (N)                 0.2568E+02  0.1660E+02 -0.1917E+02  0.5017E+02
 5 CENTRE TORQUE (Nm)               -0.1584E+01  0.5163E+00 -0.2750E+01 -0.3068E+00
 6 TOW FORCE (N)                     0.3180E+03  0.3514E+02  0.2495E+03  0.3788E+03
 7 PORT SHAFT SPEED (RPS)            0.4410E+01  0.2747E-02  0.4400E+01  0.4421E+01
 8 CENTRE SHAFT SPEED (RPS)          0.3576E+01  0.1429E-01  0.3539E+01  0.3607E+01
 9 STRBRD. SHAFT SPEED (RPS)         0.4068E+01  0.4500E-02  0.4049E+01  0.4100E+01
10 NOZZLE BN [#1 GAUGE] (Nm)        -0.3205E+01  0.7534E+00 -0.5001E+01 -0.1353E+01
11 NOZZLE BN [#2 GAUGE] (Nm)        -0.3532E+01  0.9452E+00 -0.5601E+01 -0.1289E+01
12 NOZZLE BN [#3 GAUGE] (Nm)        -0.4117E+01  0.7807E+00 -0.5993E+01 -0.2133E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.3868E+00  0.2780E+00 -0.3520E+00  0.1345E+01


GROUP NO.  17     TOTAL NO. OF SAMPLES =     2045     27-APR-1988 12:38:22

T1 =    17.0000 SEC.      T2 =    23.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 15 Kts, Vm = 1.992 m/s, VAR. SHAFT SPEED

CH DESCRIPTION                        AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              0.1996E+01  0.1841E-02  0.1992E+01  0.2011E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.5182E-01  0.3431E+00 -0.8886E+00  0.1866E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.3030E-01  0.3201E+00 -0.9473E+00  0.8633E+00
 4 CENTRE THRUST (N)                 0.1508E+02  0.5891E+01 -0.2783E+01  0.2726E+02
 5 CENTRE TORQUE (Nm)               -0.8412E-01  0.4348E+00 -0.1217E+01  0.8767E+00
 6 TOW FORCE (N)                     0.2287E+03  0.1188E+02  0.2032E+03  0.2508E+03
 7 PORT SHAFT SPEED (RPS)            0.5518E+01  0.5135E-02  0.5500E+01  0.5535E+01
 8 CENTRE SHAFT SPEED (RPS)          0.5146E+01  0.1083E-01  0.5081E+01  0.5181E+01
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  9 STRBRD. SHAFT SPEED (RPS)       0.6706E+01  0.3590E-02  0.6692E+01  0.6719E+01
 10 NOZZLE BN [#1 GAUGE] (Nm)      -0.5500E+00  0.1672E+01 -0.3832E+01  0.2579E+01
 11 NOZZLE BN [#2 GAUGE] (Nm)      -0.6711E+00  0.1857E+01 -0.4268E+01  0.2918E+01
 12 NOZZLE BN [#3 GAUGE] (Nm)      -0.9108E+00  0.2031E+01 -0.4599E+01  0.3765E+01
 13 NOZZLE TORSION [ #1 Gg] (Nm)    0.1393E+00  0.3530E+00 -0.1270E+01  0.1512E+01


GROUP NO.  17     TOTAL NO. OF SAMPLES =    2045     27-APR-1988 12:38:22

T1 =   31.0000 SEC.     T2 =   35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
OVERLOAD, Vs = 15 Kts, Vm = 1.992 m/s, VAR. SHAFT SPEED

CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM .


  1 CARRIAGE SPEED (M/S)            0.1996E+01  0.2924E-02  0.1983E+01  0.2012E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)   -0.2899E+00  0.4523E+00 -0.1512E+01  0.1216E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.1446E+00  0.4769E+00 -0.1472E+01  0.1949E+01
  4 CENTRE THRUST (N)               0.2317E+02  0.5386E+01  0.1086E+02  0.3625E+02
  5 CENTRE TORQUE (Nm)              0.1599E+01  0.6693E+00  0.9808E-01  0.3226E+01
  6 TOW FORCE (N)                   0.5920E+02  0.2188E+02  0.7637E+01  0.9739E+02
  7 PORT SHAFT SPEED (RPS)          0.9110E+01  0.3296E-02  0.9078E+01  0.9126E+01
  8 CENTRE SHAFT SPEED (RPS)        0.6385E+01  0.2103E-01  0.6340E+01  0.6428E+01
  9 STRBRD. SHAFT SPEED (RPS)       0.8880E+01  0.7475E-02  0.8869E+01  0.8922E+01
 10 NOZZLE BN [#1 GAUGE] (Nm)       0.2632E+01  0.8542E+00  0.4181E+00  0.4456E+01
 11 NOZZLE BN [#2 GAUGE] (Nm)       0.2816E+01  0.9254E+00  0.4643E+00  0.4741E+01
 12 NOZZLE BN [#3 GAUGE] (Nm)       0.2951E+01  0.9800E+00  0.4763E+00  0.5016E+01
 13 NOZZLE TORSION [ #1 Gg] (Nm)    0.3713E-01  0.4429E+00 -0.1159E+01  0.1011E+01


GROUP NO.  18     TOTAL NO. OF SAMPLES =    2530     27-APR-1988 13:01:11

T1 =    2.0000 SEC.     T2 =   25.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, ZERO STATS

CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)            0.6495E-03  0.2121E-02 -0.3312E-01  0.3104E-01
  2 NOZZLE TORSION [ #2 Gg] (Nm)    0.2859E-01  0.1032E+00 -0.1850E+01  0.1268E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)    0.7618E-01  0.1366E+00 -0.1445E+01  0.1515E+01
  4 CENTRE THRUST (N)              -0.8400E+00  0.7574E+01 -0.1371E+02  0.1310E+02
  5 CENTRE TORQUE (Nm)             -0.8591E+00  0.1683E+00 -0.1276E+01 -0.4314E+00
  6 TOW FORCE (N)                   0.7321E+01  0.1345E+01  0.6010E+00  0.1581E+02
  7 PORT SHAFT SPEED (RPS)         -0.5938E-01  0.2665E-02 -0.7727E-01 -0.3108E-01
  8 CENTRE SHAFT SPEED (RPS)       -0.9676E-01  0.4456E-02 -0.1261E+00 -0.2781E-01
  9 STRBRD. SHAFT SPEED (RPS)      -0.9379E-01  0.2363E-02 -0.1216E+00 -0.7088E-01
 10 NOZZLE BN [#1 GAUGE] (Nm)      -0.9688E-02  0.1938E+00 -0.2486E+01  0.2720E+01
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11 NOZZLE BN [#2 GAUGE] (Nm)       0.1202E+00  0.1713E+00 -0.1744E+01  0.2322E+01
12 NOZZLE BN [#3 GAUGE] (Nm)       0.1207E+00  0.2023E+00 -0.1883E+01  0.2371E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)    0.2861E+00  0.7363E-01 -0.3242E+00  0.1512E+01



GROUP NO.  19     TOTAL NO. OF SAMPLES =     717     27-APR-1988 13:06:28

T1 =    1.0000 SEC.     T2 =   14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, Vs=0, 100 % POWER, ALL SHAFTS

CH DESCRIPTION                      AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.5522E-03  0.2629E-02 -0.2198E-01  0.3594E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.6826E+00  0.5635E+00 -0.1330E+01  0.2698E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.1371E+00  0.6293E+00 -0.2612E+01  0.3253E+01
 4 CENTRE THRUST (N)               0.8009E+01  0.2449E+02 -0.5927E+02  0.5906E+02
 5 CENTRE TORQUE (Nm)             -0.6399E+01  0.4528E+00 -0.7539E+01 -0.5352E+01
 6 TOW FORCE (N)                   0.2961E+03  0.3460E+01  0.2838E+03  0.3066E+03
 7 PORT SHAFT SPEED (RPS)         -0.8403E+01  0.9078E-02 -0.8445E+01 -0.8339E+01
 8 CENTRE SHAFT SPEED (RPS)       -0.7203E+01  0.2006E-01 -0.7243E+01 -0.7117E+01
 9 STRBRD. SHAFT SPEED (RPS)      -0.8546E+01  0.6033E-02 -0.8585E+01 -0.8507E+01
10 NOZZLE BN [#1 GAUGE] (Nm)      -0.1534E+02  0.1207E+01 -0.1896E+02 -0.1131E+02
11 NOZZLE BN [#2 GAUGE] (Nm)      -0.1703E+02  0.1259E+01 -0.2046E+02 -0.1363E+02
12 NOZZLE BN [#3 GAUGE] (Nm)      -0.1879E+02  0.1337E+01 -0.2286E+02 -0.1511E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)    0.4123E+00  0.6027E+00 -0.7692E+00  0.3041E+01



GROUP NO.  20     TOTAL NO. OF SAMPLES =    1113     27-APR-1988 13:13:20

T1 =    1.0000 SEC.     T2 =   18.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, 100 % POWER, CENTRE SHAFT

CH DESCRIPTION                      AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.4873E-03  0.7097E-03 -0.1129E-01  0.8314E-02
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.6228E+00  0.5304E+00 -0.8626E+00  0.1970E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.1014E-01  0.5628E+00 -0.1608E+01  0.1026E+01
 4 CENTRE THRUST (N)               0.4257E+01  0.3151E+02 -0.6914E+02  0.6502E+02
 5 CENTRE TORQUE (Nm)             -0.6052E+01  0.4572E+00 -0.7193E+01 -0.4944E+01
 6 TOW FORCE (N)                   0.1320E+03  0.2757E+01  0.1243E+03  0.1416E+03
 7 PORT SHAFT SPEED (RPS)         -0.4422E-01  0.1666E-02 -0.5747E-01 -0.1376E-01
 8 CENTRE SHAFT SPEED (RPS)       -0.7190E+01  0.2181E-01 -0.7233E+01 -0.7145E+01
 9 STRBRD. SHAFT SPEED (RPS)      -0.1981E-02  0.1859E-02 -0.1300E-01  0.2440E-01
10 NOZZLE BN [#1 GAUGE] (Nm)      -0.1559E+02  0.1374E+01 -0.1864E+02 -0.1194E+02
11 NOZZLE BN [#2 GAUGE] (Nm)      -0.1743E+02  0.1464E+01 -0.2053E+02 -0.1335E+02
12 NOZZLE BN [#3 GAUGE] (Nm)      -0.1934E+02  0.1581E+01 -0.2361E+02 -0.1518E+02
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13 NOZZLE TORSION [ #1 Gg] (Nm)    0.3455E+00  0.5655E+00 -0.7970E+00  0.1400E+01


GROUP NO.  21     TOTAL NO. OF SAMPLES =     810     27-APR-1988 13:25:16

T1 =    1.0000 SEC.     T2 =   15.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, 75% POWER, ALL SHAFTS

CH DESCRIPTION                       AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             0.3418E-03  0.2062E-02 -0.2466E-01  0.1678E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.2872E+00  0.4191E+00 -0.2240E+01  0.2516E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.1114E+00  0.4091E+00 -0.1553E+01  0.2357E+01
 4 CENTRE THRUST (N)                0.8772E+01  0.1718E+02 -0.2764E+02  0.3682E+02
 5 CENTRE TORQUE (Nm)              -0.3741E+01  0.2986E+00 -0.4587E+01 -0.2975E+01
 6 TOW FORCE (N)                    0.1939E+03  0.3155E+01  0.1823E+03  0.2031E+03
 7 PORT SHAFT SPEED (RPS)          -0.7119E+01  0.4994E-02 -0.7138E+01 -0.7088E+01
 8 CENTRE SHAFT SPEED (RPS)        -0.5848E+01  0.1481E-01 -0.5903E+01 -0.5765E+01
 9 STRBRD. SHAFT SPEED (RPS)       -0.7191E+01  0.6929E-02 -0.7234E+01 -0.7156E+01
10 NOZZLE BN [#1 GAUGE] (Nm)       -0.1000E+02  0.9971E+00 -0.1283E+02 -0.6701E+01
11 NOZZLE BN [#2 GAUGE] (Nm)       -0.1100E+02  0.1053E+01 -0.1359E+02 -0.6757E+01
12 NOZZLE BN [#3 GAUGE] (Nm)       -0.1215E+02  0.1139E+01 -0.1486E+02 -0.9031E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)     0.2744E+00  0.4384E+00 -0.2911E+01  0.2151E+01


GROUP NO.  22     TOTAL NO. OF SAMPLES =     752     27-APR-1988 13:32:56

T1 =    1.0000 SEC.     T2 =   14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, 50% POWER, ALL SHAFTS

CH DESCRIPTION                       AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             0.5104E-03  0.1975E-02 -0.2867E-01  0.1455E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.2052E+00  0.2878E+00 -0.1720E+01  0.8526E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.7340E-01  0.4604E+00 -0.3101E+01  0.7488E+01
 4 CENTRE THRUST (N)               -0.1404E+01  0.1674E+02 -0.3460E+02  0.2245E+02
 5 CENTRE TORQUE (Nm)              -0.2865E+01  0.2668E+00 -0.3601E+01 -0.2196E+01
 6 TOW FORCE (N)                    0.1215E+03  0.1933E+02  0.8535E+02  0.1595E+03
 7 PORT SHAFT SPEED (RPS)          -0.5317E+01  0.3876E-02 -0.5357E+01 -0.5291E+01
 8 CENTRE SHAFT SPEED (RPS)        -0.4947E+01  0.1372E-01 -0.5016E+01 -0.4903E+01
 9 STRBRD. SHAFT SPEED (RPS)       -0.5317E+01  0.6258E-02 -0.5345E+01 -0.5293E+01
10 NOZZLE BN [#1 GAUGE] (Nm)       -0.6978E+01  0.5279E+00 -0.1109E+02 -0.3443E+01
11 NOZZLE BN [#2 GAUGE] (Nm)       -0.7826E+01  0.4830E+00 -0.9632E+01 -0.4934E+01
12 NOZZLE BN [#3 GAUGE] (Nm)       -0.8706E+01  0.4683E+00 -0.1010E+02 -0.6422E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)     0.3270E+00  0.3350E+00 -0.1826E+01  0.2708E+01
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GROUP NO.  23     TOTAL NO. OF SAMPLES =     878     27-APR-1988 13:35:57

T1 =     6.0000 SEC.      T2 =    14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN ZERO STATS.


CH DESCRIPTION                              AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                   0.6853E-03  0.1384E-02 -0.1797E-01  0.1366E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)           0.3127E-01  0.8952E-01 -0.1304E+01  0.2289E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)           0.3294E-01  0.1802E+00 -0.1580E+01  0.2031E+01
 4 CENTRE THRUST (N)                      0.2564E+01  0.3288E+01 -0.7030E+01  0.9601E+01
 5 CENTRE TORQUE (Nm)                    -0.5302E+00  0.1542E+00 -0.9608E+00 -0.1891E+00
 6 TOW FORCE (N)                          0.3621E+01  0.7669E+01 -0.1200E+02  0.2277E+02
 7 PORT SHAFT SPEED (RPS)                -0.3902E-01  0.1555E-02 -0.5170E-01 -0.2613E-01
 8 CENTRE SHAFT SPEED (RPS)              -0.5183E-01  0.4440E-02 -0.7017E-01  0.9958E-03
 9 STRBRD. SHAFT SPEED (RPS)             -0.3861E-01  0.2872E-02 -0.7266E-01 -0.2012E-01
10 NOZZLE BN [#1 GAUGE] (Nm)             -0.2408E-01  0.1823E+00 -0.2982E+01  0.6306E+00
11 NOZZLE BN [#2 GAUGE] (Nm)             -0.1006E-01  0.2364E+00 -0.2901E+01  0.2287E+01
12 NOZZLE BN [#3 GAUGE] (Nm)             -0.3235E-02  0.2370E+00 -0.2490E+01  0.2978E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)           0.3998E+00  0.8373E-01 -0.2964E+00  0.1039E+01




GROUP NO.  24     TOTAL NO. OF SAMPLES =    1050     27-APR-1988 14:06:26

T1 =     1.0000 SEC.      T2 =    19.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, 50% POWER, REPEAT


CH DESCRIPTION                              AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                   0.4425E-03  0.2375E-02 -0.3000E-01  0.2257E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)           0.2545E+00  0.2889E+00 -0.1356E+01  0.2646E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          -0.3521E-01  0.3297E+00 -0.3074E+01  0.2384E+01
 4 CENTRE THRUST (N)                     -0.4164E+02  0.8578E+01 -0.5624E+02 -0.2549E+02
 5 CENTRE TORQUE (Nm)                    -0.3114E+01  0.2814E+00 -0.3871E+01 -0.2376E+01
 6 TOW FORCE (N)                          0.1163E+03  0.9559E+01  0.9339E+02  0.1410E+03
 7 PORT SHAFT SPEED (RPS)                -0.5335E+01  0.4028E-02 -0.5362E+01 -0.5285E+01
 8 CENTRE SHAFT SPEED (RPS)              -0.4863E+01  0.1162E-01 -0.4935E+01 -0.4788E+01
 9 STRBRD. SHAFT SPEED (RPS)             -0.5307E+01  0.6723E-02 -0.5330E+01 -0.5277E+01
10 NOZZLE BN [#1 GAUGE] (Nm)             -0.7632E+01  0.5357E+00 -0.9747E+01 -0.5107E+01
11 NOZZLE BN [#2 GAUGE] (Nm)             -0.8132E+01  0.5580E+00 -0.1110E+02 -0.6337E+01
12 NOZZLE BN [#3 GAUGE] (Nm)             -0.8741E+01  0.5899E+00 -0.1139E+02 -0.5526E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)           0.3523E+00  0.3389E+00 -0.2549E+01  0.2207E+01
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GROUP NO.  25     TOTAL NO. OF SAMPLES =     1901     27-APR-1988 14:09:06

T1 =     1.0000 SEC.      T2 =   35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, 25 % POWER


CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 0.5658E-03  0.2450E-02 -0.2733E-01  0.3460E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)         0.1043E+00  0.1981E+00 -0.1902E+01  0.2334E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)        -0.4616E-01  0.2007E+00 -0.1635E+01  0.2139E+01
 4 CENTRE THRUST (N)                   -0.2498E+02  0.7773E+01 -0.3937E+02 -0.9055E+01
 5 CENTRE TORQUE (Nm)                  -0.1934E+01  0.2524E+00 -0.2674E+01 -0.1210E+01
 6 TOW FORCE (N)                        0.6218E+02  0.3713E+01  0.4993E+02  0.7471E+02
 7 PORT SHAFT SPEED (RPS)              -0.4115E+01  0.2551E-02 -0.4156E+01 -0.4086E+01
 8 CENTRE SHAFT SPEED (RPS)            -0.3571E+01  0.1157E-01 -0.3623E+01 -0.3508E+01
 9 STRBRD. SHAFT SPEED (RPS)           -0.4091E+01  0.3866E-02 -0.4131E+01 -0.4066E+01
10 NOZZLE BN [#1 GAUGE] (Nm)           -0.3551E+01  0.3257E+00 -0.6311E+01 -0.5028E+00
11 NOZZLE BN [#2 GAUGE] (Nm)           -0.3767E+01  0.3575E+00 -0.8230E+01 -0.7276E+00
12 NOZZLE BN [#3 GAUGE] (Nm)           -0.4106E+01  0.3144E+00 -0.6279E+01 -0.2276E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)         0.3410E+00  0.1962E+00 -0.1910E+01  0.2012E+01




GROUP NO.  26     TOTAL NO. OF SAMPLES =     2702     27-APR-1988 14:12:54

T1 =     1.0000 SEC.      T2 =   50.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN BOLLARD, ZERO STATS.


CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 0.8002E-03  0.1807E-02 -0.2599E-01  0.3237E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)         0.2139E-01  0.1220E+00 -0.2032E+01  0.2178E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)         0.3774E-01  0.1336E+00 -0.1988E+01  0.2112E+01
 4 CENTRE THRUST (N)                   -0.1988E+01  0.6243E+01 -0.1379E+02  0.9565E+01
 5 CENTRE TORQUE (Nm)                  -0.7612E+00  0.2673E+00 -0.1573E+01 -0.1580E+00
 6 TOW FORCE (N)                       -0.2015E+00  0.2076E+01 -0.8961E+01  0.1516E+02
 7 PORT SHAFT SPEED (RPS)               0.1574E+00  0.1824E-02  0.1298E+00  0.1858E+00
 8 CENTRE SHAFT SPEED (RPS)            -0.6608E+00  0.5107E-02 -0.7276E+00 -0.6107E+00
 9 STRBRD. SHAFT SPEED (RPS)           -0.2873E-01  0.2132E-02 -0.5218E-01  0.5704E-02
10 NOZZLE BN [#1 GAUGE] (Nm)            0.5550E+00  0.2265E+00 -0.2451E+01  0.3464E+01
11 NOZZLE BN [#2 GAUGE] (Nm)            0.7390E+00  0.2300E+00 -0.1324E+01  0.3584E+01
12 NOZZLE BN [#3 GAUGE] (Nm)            0.4347E+00  0.1578E+00 -0.9891E+00  0.2371E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)         0.4135E+00  0.1318E+00 -0.9083E+00  0.2680E+01
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GROUP NO.  27     TOTAL NO. OF SAMPLES =    3692     27-APR-1988 14:19:53

T1 =    6.0000 SEC.     T2 =   14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-2.0 KTS, Vm=-0.265 M/S, V/P


CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.2653E+00  0.3800E-03 -0.2685E+00 -0.2642E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.9530E-01  0.2050E+00 -0.1252E+01  0.2334E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.2766E-01  0.1327E+00 -0.4943E+00  0.5375E+00
 4 CENTRE THRUST (N)                 -0.2139E+02  0.8098E+01 -0.3547E+02 -0.6907E+01
 5 CENTRE TORQUE (Nm)                -0.1675E+01  0.2678E+00 -0.2528E+01 -0.9746E+00
 6 TOW FORCE (N)                      0.4254E+02  0.1024E+02  0.2537E+02  0.6449E+02
 7 PORT SHAFT SPEED (RPS)            -0.4006E+01  0.3190E-02 -0.4047E+01 -0.3981E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.3512E+01  0.1176E-01 -0.3559E+01 -0.3454E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.4105E+01  0.3693E-02 -0.4118E+01 -0.4074E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.1134E+01  0.3034E+00 -0.4470E+01  0.8077E+00
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.1273E+01  0.2802E+00 -0.3637E+01  0.8499E+00
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.2029E+01  0.3147E+00 -0.3991E+01  0.1155E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.4237E+00  0.1485E+00 -0.8526E+00  0.7606E+00
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GROUP NO.  27     TOTAL NO. OF SAMPLES =    3692     27-APR-1988 14:19:53

T1 =   21.0000 SEC.     T2 =   31.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-2.0 KTS, Vm=-0.265 M/S, V/P


CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.2653E+00  0.4052E-03 -0.2680E+00 -0.2608E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.2826E+00  0.3149E+00 -0.1123E+01  0.2360E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.4932E-01  0.3118E+00 -0.6572E+00  0.1977E+01
 4 CENTRE THRUST (N)                 -0.4680E+02  0.8112E+01 -0.6046E+02 -0.3237E+02
 5 CENTRE TORQUE (Nm)                -0.3333E+01  0.2926E+00 -0.4297E+01 -0.2660E+01
 6 TOW FORCE (N)                      0.1085E+03  0.8718E+01  0.8992E+02  0.1277E+03
 7 PORT SHAFT SPEED (RPS)            -0.5504E+01  0.3825E-02 -0.5522E+01 -0.5475E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.5357E+01  0.1318E-01 -0.5391E+01 -0.5281E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.5351E+01  0.6692E-02 -0.5381E+01 -0.5322E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.5249E+01  0.7243E+00 -0.7409E+01 -0.2486E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.5920E+01  0.7902E+00 -0.9352E+01 -0.3813E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.7214E+01  0.8215E+00 -0.9281E+01 -0.4992E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.4514E+00  0.3590E+00 -0.2549E+01  0.2235E+01
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GROUP NO.  27     TOTAL NO. OF SAMPLES =    3692     27-APR-1988 14:19:53
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T1 =   39.0000 SEC.     T2 =   46.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-2.0 KTS, Vm=-0.265 M/S, V/P


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.2653E+00  0.4756E-03 -0.2669E+00 -0.2593E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.3339E+00  0.4055E+00 -0.1019E+01  0.3243E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.3328E-01  0.4227E+00 -0.1798E+01  0.2139E+01
 4 CENTRE THRUST (N)                -0.6178E+02  0.8382E+01 -0.7677E+02 -0.4697E+02
 5 CENTRE TORQUE (Nm)               -0.4264E+01  0.3276E+00 -0.5103E+01 -0.3445E+01
 6 TOW FORCE (N)                     0.1837E+03  0.8377E+01  0.1684E+03  0.2038E+03
 7 PORT SHAFT SPEED (RPS)           -0.7383E+01  0.5307E-02 -0.7426E+01 -0.7355E+01
 8 CENTRE SHAFT SPEED (RPS)         -0.6216E+01  0.1214E-01 -0.6243E+01 -0.6167E+01
 9 STRBRD. SHAFT SPEED (RPS)        -0.7345E+01  0.6127E-02 -0.7368E+01 -0.7327E+01
10 NOZZLE BN [#1 GAUGE] (Nm)        -0.7867E+01  0.5867E+00 -0.1028E+02 -0.4753E+01
11 NOZZLE BN [#2 GAUGE] (Nm)        -0.8852E+01  0.5396E+00 -0.1075E+02 -0.7529E+01
12 NOZZLE BN [#3 GAUGE] (Nm)        -0.1044E+02  0.5728E+00 -0.1271E+02 -0.8638E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.4379E+00  0.4233E+00 -0.6301E+00  0.2151E+01




GROUP NO.  27     TOTAL NO. OF SAMPLES =    3692     27-APR-1988 14:19:53

T1 =   53.0000 SEC.     T2 =   68.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-2.0 KTS, Vm=-0.265 M/S, V/P


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.2653E+00  0.5406E-03 -0.2737E+00 -0.2609E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.4672E+00  0.4793E+00 -0.7327E+00  0.3633E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2598E-01  0.5018E+00 -0.2069E+01  0.2221E+01
 4 CENTRE THRUST (N)                -0.8454E+02  0.9055E+01 -0.1045E+03 -0.6547E+02
 5 CENTRE TORQUE (Nm)               -0.5409E+01  0.3891E+00 -0.6335E+01 -0.4248E+01
 6 TOW FORCE (N)                     0.2581E+03  0.9880E+01  0.2353E+03  0.2855E+03
 7 PORT SHAFT SPEED (RPS)           -0.8565E+01  0.3973E-02 -0.8595E+01 -0.8529E+01
 8 CENTRE SHAFT SPEED (RPS)         -0.7087E+01  0.1236E-01 -0.7145E+01 -0.7041E+01
 9 STRBRD. SHAFT SPEED (RPS)        -0.8715E+01  0.5359E-02 -0.8739E+01 -0.8694E+01
10 NOZZLE BN [#1 GAUGE] (Nm)        -0.1121E+02  0.7344E+00 -0.1474E+02 -0.9322E+01
11 NOZZLE BN [#2 GAUGE] (Nm)        -0.1258E+02  0.7738E+00 -0.1612E+02 -0.8861E+01
12 NOZZLE BN [#3 GAUGE] (Nm)        -0.1447E+02  0.7179E+00 -0.1593E+02 -0.1250E+02
13 NOZZLE TORSION [ #1 Gg] (Nm)      0.4369E+00  0.5201E+00 -0.3467E+01  0.2374E+01




GROUP NO.  28     TOTAL NO. OF SAMPLES =    3350     27-APR-1988 14:29:12

T1 =    1.0000 SEC.     T2 =   10.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-4.0 KTS, Vm=-0.531 M/S, V/P

CH DESCRIPTION                          AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.5318E+00  0.3145E-03 -0.5336E+00 -0.5287E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.1486E-02  0.1605E+00 -0.1123E+01  0.1086E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.4571E-01  0.1716E+00 -0.1553E+01  0.1298E+01
 4 CENTRE THRUST (N)                 -0.2423E+02  0.7987E+01 -0.3858E+02 -0.9732E+01
 5 CENTRE TORQUE (Nm)                -0.1520E+01  0.2980E+00 -0.2321E+01 -0.7636E+00
 6 TOW FORCE (N)                      0.1184E+02  0.2360E+02 -0.5742E+02  0.6819E+02
 7 PORT SHAFT SPEED (RPS)            -0.3996E+01  0.1947E-02 -0.4006E+01 -0.3984E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.3500E+01  0.1319E-01 -0.3568E+01 -0.3457E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.4158E+01  0.5300E-02 -0.4176E+01 -0.4120E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.9226E-02  0.2466E+00 -0.2097E+01  0.3785E+00
11 NOZZLE BN [#2 GAUGE] (Nm)          0.2113E+00  0.2926E+00 -0.1008E+01  0.3269E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.2840E+00  0.2946E+00 -0.2883E+01  0.1549E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.4576E+00  0.1899E+00 -0.3798E+00  0.2346E+01



GROUP NO.  28     TOTAL NO. OF SAMPLES =    3350     27-APR-1988 14:29:12

T1 =   18.5000 SEC.     T2 =   28.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-4.0 KTS, Vm=-0.531 M/S, V/P

CH DESCRIPTION                          AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.5319E+00  0.3566E-03 -0.5336E+00 -0.5282E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.5121E-01  0.2759E+00 -0.1538E+01  0.1762E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.1546E-01  0.3362E+00 -0.2911E+01  0.2302E+01
 4 CENTRE THRUST (N)                 -0.3985E+02  0.8512E+01 -0.5501E+02 -0.2549E+02
 5 CENTRE TORQUE (Nm)                -0.2501E+01  0.3090E+00 -0.3324E+01 -0.1750E+01
 6 TOW FORCE (N)                      0.5990E+02  0.1073E+02  0.3494E+02  0.8427E+02
 7 PORT SHAFT SPEED (RPS)            -0.5454E+01  0.3402E-02 -0.5464E+01 -0.5435E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.4756E+01  0.1362E-01 -0.4798E+01 -0.4718E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.5319E+01  0.6240E-02 -0.5334E+01 -0.5291E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.2015E+01  0.4766E+00 -0.4859E+01  0.1304E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.2083E+01  0.4726E+00 -0.3602E+01  0.1236E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.2810E+01  0.4215E+00 -0.3884E+01 -0.1775E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.4390E+00  0.2877E+00 -0.8526E+00  0.2346E+01



GROUP NO.  28     TOTAL NO. OF SAMPLES =    3350     27-APR-1988 14:29:12

T1 =   38.0000 SEC.     T2 =   44.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-4.0 KTS, Vm=-0.531 M/S, V/P
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CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.5321E+00  0.2923E-03 -0.5335E+00 -0.5296E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.3782E-02  0.3619E+00 -0.1954E+01  0.1398E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.1622E+00  0.3370E+00 -0.9559E+00  0.9719E+00
 4 CENTRE THRUST (N)                 -0.6088E+02  0.8487E+01 -0.7602E+02 -0.4570E+02
 5 CENTRE TORQUE (Nm)                -0.3812E+01  0.3444E+00 -0.4636E+01 -0.2919E+01
 6 TOW FORCE (N)                      0.1373E+03  0.4467E+01  0.1277E+03  0.1492E+03
 7 PORT SHAFT SPEED (RPS)            -0.7354E+01  0.3460E-02 -0.7363E+01 -0.7339E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.6043E+01  0.1369E-01 -0.6075E+01 -0.5996E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.7277E+01  0.5987E-02 -0.7302E+01 -0.7242E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.4954E+01  0.4775E+00 -0.6949E+01 -0.3443E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.5444E+01  0.5092E+00 -0.7283E+01 -0.3147E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.6589E+01  0.5433E+00 -0.9389E+01 -0.4599E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.2860E+00  0.4102E+00 -0.5467E+00  0.2958E+01




GROUP NO.  28     TOTAL NO. OF SAMPLES =     3350      27-APR-1988 14:29:12

T1 =   55.0000 SEC.      T2 =   65.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOAD, Vs=-4.0 KTS, Vm=-0.531 M/S, V/P

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.5324E+00  0.3756E-03 -0.5334E+00 -0.5283E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.2238E+00  0.4363E+00 -0.1512E+01  0.2204E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.4255E-01  0.4744E+00 -0.1309E+01  0.2194E+01
 4 CENTRE THRUST (N)                 -0.8043E+02  0.8675E+01 -0.9722E+02 -0.6352E+02
 5 CENTRE TORQUE (Nm)                -0.5010E+01  0.4237E+00 -0.6189E+01 -0.3916E+01
 6 TOW FORCE (N)                      0.2057E+03  0.1368E+02  0.1740E+03  0.2340E+03
 7 PORT SHAFT SPEED (RPS)            -0.8460E+01  0.4307E-02 -0.8511E+01 -0.8431E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.7032E+01  0.1275E-01 -0.7080E+01 -0.6997E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.8694E+01  0.5026E-02 -0.8710E+01 -0.8662E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.7703E+01  0.6356E+00 -0.1021E+02 -0.5001E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.8533E+01  0.6692E+00 -0.1124E+02 -0.5951E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.1003E+02  0.6457E+00 -0.1143E+02 -0.7458E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.3951E+00  0.5030E+00 -0.2299E+01  0.3264E+01




GROUP NO.  29     TOTAL NO. OF SAMPLES =     3097      27-APR-1988 14:40:48

T1 =    1.0000 SEC.      T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOADS, Vs=-6.0 KTS, Vm=-0.747 M/S, V/P
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CH DESCRIPTION                          AVERAGE        RMS        MINIMUM       MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.7989E+00  0.3463E-03 -0.8000E+00 -0.7956E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.2289E-01  0.1636E+00 -0.6027E+00  0.1996E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.2596E-01  0.1166E+00 -0.7930E+00  0.4017E+00
 4 CENTRE THRUST (N)                 -0.7172E+01  0.7724E+01 -0.2151E+02  0.7058E+01
 5 CENTRE TORQUE (Nm)                -0.1284E+01  0.2768E+00 -0.2061E+01 -0.6217E+00
 6 TOW FORCE (N)                     -0.2729E+02  0.2406E+02 -0.9089E+02  0.2885E+02
 7 PORT SHAFT SPEED (RPS)            -0.4033E+01  0.2526E-02 -0.4056E+01 -0.4010E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.3524E+01  0.1270E-01 -0.3590E+01 -0.3501E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.4121E+01  0.3045E-02 -0.4137E+01 -0.4101E+01
10 NOZZLE BN [#1 GAUGE] (Nm)          0.1502E+01  0.2384E+00  0.4889E+00  0.3429E+01
11 NOZZLE BN [#2 GAUGE] (Nm)          0.1604E+01  0.2495E+00  0.8149E+00  0.4426E+01
12 NOZZLE BN [#3 GAUGE] (Nm)          0.1136E+01  0.2137E+00 -0.5602E+00  0.2156E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.4415E+00  0.1655E+00 -0.7385E-01  0.2958E+01



GROUP NO.  29     TOTAL NO. OF SAMPLES =     3097     27-APR-1988 14:40:48

T1 =   18.0000 SEC.     T2 =   25.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOADS, Vs=-6.0 KTS, Vm=-0.747 M/S, V/P

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM       MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.7995E+00  0.3606E-03 -0.8007E+00 -0.7979E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.1628E+00  0.2592E+00 -0.4728E+00  0.9046E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.1442E+00  0.2830E+00 -0.7930E+00  0.1461E+01
 4 CENTRE THRUST (N)                 -0.3240E+02  0.8713E+01 -0.4848E+02 -0.1709E+02
 5 CENTRE TORQUE (Nm)                -0.2839E+01  0.3199E+00 -0.3743E+01 -0.2054E+01
 6 TOW FORCE (N)                      0.2155E+02  0.1231E+02 -0.7005E+01  0.4428E+02
 7 PORT SHAFT SPEED (RPS)            -0.5291E+01  0.2854E-02 -0.5306E+01 -0.5268E+01
 8 CENTRE SHAFT SPEED (RPS)          -0.5387E+01  0.1430E-01 -0.5450E+01 -0.5335E+01
 9 STRBRD. SHAFT SPEED (RPS)         -0.5266E+01  0.5181E-02 -0.5279E+01 -0.5244E+01
10 NOZZLE BN [#1 GAUGE] (Nm)         -0.4433E+00  0.1621E+01 -0.3230E+01  0.2260E+01
11 NOZZLE BN [#2 GAUGE] (Nm)         -0.5923E+00  0.1780E+01 -0.3672E+01  0.2533E+01
12 NOZZLE BN [#3 GAUGE] (Nm)         -0.1447E+01  0.1978E+01 -0.5528E+01  0.1942E+01
13 NOZZLE TORSION [ #1 Gg] (Nm)       0.5285E+00  0.2928E+00 -0.7385E-01  0.2374E+01



GROUP NO.  29     TOTAL NO. OF SAMPLES =     3097     27-APR-1988 14:40:48

T1 =   35.0000 SEC.     T2 =   42.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOADS, Vs=-6.0 KTS, Vm=-0.747 M/S, V/P

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM       MAXIMUM
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  1 CARRIAGE SPEED (M/S)             -0.8003E+00  0.3783E-03 -0.8038E+00 -0.7984E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1196E+00  0.3714E+00 -0.1071E+01  0.1242E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2585E-01  0.3975E+00 -0.1635E+01  0.6732E+00
  4 CENTRE THRUST (N)                -0.5308E+02  0.8599E+01 -0.7144E+02 -0.3977E+02
  5 CENTRE TORQUE (Nm)               -0.4282E+01  0.4111E+00 -0.5362E+01 -0.3393E+01
  6 TOW FORCE (N)                     0.9363E+02  0.6779E+01  0.7862E+02  0.1119E+03
  7 PORT SHAFT SPEED (RPS)           -0.7140E+01  0.3519E-02 -0.7158E+01 -0.7109E+01
  8 CENTRE SHAFT SPEED (RPS)         -0.6586E+01  0.1392E-01 -0.6619E+01 -0.6548E+01
  9 STRBRD. SHAFT SPEED (RPS)        -0.7064E+01  0.5095E-02 -0.7095E+01 -0.7045E+01
 10 NOZZLE BN [#1 GAUGE] (Nm)        -0.3004E+01  0.5850E+00 -0.4222E+01 -0.4320E+00
 11 NOZZLE BN [#2 GAUGE] (Nm)        -0.3542E+01  0.5814E+00 -0.4759E+01 -0.2165E+01
 12 NOZZLE BN [#3 GAUGE] (Nm)        -0.4792E+01  0.6116E+00 -0.6887E+01 -0.2204E+01
 13 NOZZLE TORSION [ #1 Gg] (Nm)      0.3986E+00  0.4489E+00 -0.9639E+00  0.2346E+01



GROUP NO.  29     TOTAL NO. OF SAMPLES =     3097     27-APR-1988 14:40:48

T1 =    49.0000 SEC.      T2 =    59.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOADS, Vs=-6.0 KTS, Vm=-0.747 M/S, V/P

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


  1 CARRIAGE SPEED (M/S)             -0.8006E+00  0.5301E-03 -0.8076E+00 -0.7967E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.3645E+00  0.5611E+00 -0.1123E+01  0.2542E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2596E-01  0.5910E+00 -0.1472E+01  0.9991E+00
  4 CENTRE THRUST (N)                -0.1016E+03  0.9439E+01 -0.1221E+03 -0.8381E+02
  5 CENTRE TORQUE (Nm)               -0.7042E+01  0.4632E+00 -0.8304E+01 -0.5785E+01
  6 TOW FORCE (N)                     0.2013E+03  0.1207E+02  0.1740E+03  0.2377E+03
  7 PORT SHAFT SPEED (RPS)           -0.8521E+01  0.3930E-02 -0.8563E+01 -0.8488E+01
  8 CENTRE SHAFT SPEED (RPS)         -0.8515E+01  0.1402E-01 -0.8595E+01 -0.8426E+01
  9 STRBRD. SHAFT SPEED (RPS)        -0.8648E+01  0.5531E-02 -0.8681E+01 -0.8620E+01
 10 NOZZLE BN [#1 GAUGE] (Nm)        -0.9100E+01  0.9000E+00 -0.1134E+02 -0.6347E+01
 11 NOZZLE BN [#2 GAUGE] (Nm)        -0.1042E+02  0.9330E+00 -0.1328E+02 -0.8160E+01
 12 NOZZLE BN [#3 GAUGE] (Nm)        -0.1246E+02  0.9184E+00 -0.1479E+02 -0.9424E+01
 13 NOZZLE TORSION [ #1 Gg] (Nm)      0.3841E+00  0.6532E+00 -0.1576E+01  0.4488E+01



GROUP NO.  30     TOTAL NO. OF SAMPLES =     3406     27-APR-1988 14:47:48

T1 =     5.0000 SEC.      T2 =    50.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION
ASTERN OVERLOADS, END OF TEST ZERO STATS

CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


  1 CARRIAGE SPEED (M/S)             -0.9331E-04  0.1871E-03 -0.2193E-02  0.4043E-02
  2 NOZZLE TORSION [ #2 Gg] (Nm)  -0.1966E-02  0.9322E-01 -0.9146E+00  0.2126E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)   0.5725E-01  0.9407E-01 -0.2069E+01  0.1135E+01
  4 CENTRE THRUST (N)             -0.8773E+01  0.6266E+01 -0.2020E+02  0.2841E+01
  5 CENTRE TORQUE (Nm)            -0.9793E+00  0.2774E+00 -0.1729E+01 -0.3345E+00
  6 TOW FORCE (N)                  0.4772E+00  0.2436E+01 -0.1113E+02  0.9511E+01
  7 PORT SHAFT SPEED (RPS)         0.1245E+00  0.2227E-02  0.8439E-01  0.1594E+00
  8 CENTRE SHAFT SPEED (RPS)      -0.7325E+00  0.4427E-02 -0.7700E+00 -0.6853E+00
  9 STRBRD. SHAFT SPEED (RPS)     -0.1502E-02  0.1861E-02 -0.4238E-01  0.2084E-01
 10 NOZZLE BN [#1 GAUGE] (Nm)      0.4362E+00  0.1765E+00 -0.2557E+01  0.3216E+01
 11 NOZZLE BN [#2 GAUGE] (Nm)      0.7408E+00  0.2021E+00 -0.1990E+01  0.3690E+01
 12 NOZZLE BN [#3 GAUGE] (Nm)      0.4406E+00  0.1640E+00 -0.1990E+01  0.2085E+01
 13 NOZZLE TORSION [ #1 Gg] (Nm)   0.4204E+00  0.1134E+00 -0.1353E+01  0.2680E+01
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# APPENDIX H

# DETAILED DATA ON THE BLOCKAGE TESTS

TEST # 194

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GROUP NO.   1     TOTAL NO. OF SAMPLES =     807     27-APR-1988 16:17:12

T1 =    7.0000 SEC.     T2 =    14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
ZERO STATS CHECK


CH DESCRIPTION                           AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1186E+01  0.3692E-02 -0.1217E+01 -0.1165E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.2452E-01  0.1378E+00 -0.8338E+00  0.1323E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.7498E-02  0.9291E-01 -0.8319E+00  0.2542E+00
 4 CENTRE THRUST (N)                   0.1341E+00  0.2670E+01 -0.7114E+01  0.5857E+01
 5 CENTRE TORQUE (Nm)                 -0.2775E+00  0.2014E+00 -0.7255E+00  0.1777E+00
 6 SUCT. UPPER BENDING (Nm)            0.1537E+00  0.7946E-01 -0.8223E+00  0.8567E+00
 7 SUCT. LOWER BENDING (Nm)            0.1130E+00  0.1354E+00 -0.1548E+01  0.4779E+00
 8 SUCT. TORSION (Nm)                 -0.4509E-01  0.1161E+00 -0.9254E+00  0.9496E+00
 9 TOW FORCE (N)                       0.3905E+00  0.5836E+01 -0.1352E+02  0.1147E+02
10 PORT SHAFT SPEED (RPS)              0.1043E+00  0.1451E-02  0.9016E-01  0.1083E+00
11 CENTRE SHAFT SPEED (RPS)            0.9208E-01  0.3029E-02  0.6369E-01  0.1145E+00
12 STRBRD. SHAFT SPEED (RPS)          -0.1527E-02  0.1571E-02 -0.1656E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          -0.3044E+00  0.1325E+00 -0.1456E+01  0.5627E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          -0.1506E+00  0.1839E+00 -0.1252E+01  0.2183E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          -0.8854E-02  0.2170E+00 -0.1215E+01  0.1824E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)        0.3082E-02  0.1062E+00 -0.9176E+00  0.6122E+00
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GROUP NO.   2     TOTAL NO. OF SAMPLES =    4718     27-APR-1988 16:23:02

T1 =    1.0000 SEC.     T2 =     9.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs = 0,BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                           AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1018E+01  0.5902E-02 -0.1065E+01 -0.1011E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        0.9217E+01  0.8270E+00  0.7638E+01  0.1146E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.9209E+01  0.8257E+00  0.7612E+01  0.1144E+02
 4 CENTRE THRUST (N)                   0.1070E+03  0.1160E+02  0.7314E+02  0.1336E+03
 5 CENTRE TORQUE (Nm)                  0.6768E+01  0.6505E+00  0.5275E+01  0.8060E+01
 6 SUCT. UPPER BENDING (Nm)            0.2838E+01  0.1574E+01 -0.8042E+00  0.6183E+01
 7 SUCT. LOWER BENDING (Nm)            0.2179E+01  0.1007E+01  0.1986E-01  0.4212E+01
 8 SUCT. TORSION (Nm)                  0.1929E+00  0.4545E+00 -0.5658E+00  0.1386E+01
 9 TOW FORCE (N)                      -0.4588E+02  0.7740E+01 -0.6850E+02 -0.2743E+02
10 PORT SHAFT SPEED (RPS)             -0.4903E-01  0.7667E-03 -0.5665E-01 -0.4427E-01
11 CENTRE SHAFT SPEED (RPS)            0.7026E+01  0.2706E-01  0.6969E+01  0.7092E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.2284E-02  0.1363E-02 -0.1923E-01  0.3032E-02
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13 NOZZLE BN [#1 GAUGE] (Nm)      -0.1130E+02  0.2169E+01 -0.1739E+02 -0.6131E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.1199E+02  0.2359E+01 -0.1850E+02 -0.6546E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.1345E+02  0.2626E+01 -0.2055E+02 -0.7612E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.9138E+01  0.8240E+00  0.7510E+01  0.1132E+02


GROUP NO.   2     TOTAL NO. OF SAMPLES =    4718     27-APR-1988 16:23:02

T1 =   29.0000 SEC.      T2 =   44.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs = 0,BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                      AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1008E+01  0.1804E-02 -0.1019E+01 -0.9968E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.6352E+01  0.4233E+00  0.4936E+01  0.7560E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.6406E+01  0.4241E+00  0.5250E+01  0.8020E+01
 4 CENTRE THRUST (N)               0.6786E+02  0.7438E+01  0.4696E+02  0.8499E+02
 5 CENTRE TORQUE (Nm)              0.4602E+01  0.5552E+00  0.3299E+01  0.5873E+01
 6 SUCT. UPPER BENDING (Nm)        0.2071E+01  0.4579E+00  0.7123E+00  0.3402E+01
 7 SUCT. LOWER BENDING (Nm)        0.1623E+01  0.2988E+00  0.5659E+00  0.2504E+01
 8 SUCT. TORSION (Nm)             -0.6287E-02  0.2180E+00 -0.2055E+01  0.8212E+00
 9 TOW FORCE (N)                  -0.3034E+02  0.5924E+01 -0.4808E+02 -0.1330E+02
10 PORT SHAFT SPEED (RPS)          -0.4899E-01  0.1098E-02 -0.5830E-01 -0.4015E-01
11 CENTRE SHAFT SPEED (RPS)        0.5688E+01  0.1872E-01  0.5632E+01  0.5744E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.2159E-02  0.1868E-02 -0.1122E-01  0.2618E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.6600E+01  0.1379E+01 -0.1091E+02 -0.2767E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.6946E+01  0.1495E+01 -0.1159E+02 -0.2830E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.7784E+01  0.1660E+01 -0.1308E+02 -0.3395E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.6358E+01  0.4105E+00  0.4729E+01  0.7510E+01


GROUP NO.   2     TOTAL NO. OF SAMPLES =    4718     27-APR-1988 16:23:02

T1 =   56.0000 SEC.      T2 =   68.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs = 0,BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                      AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1003E+01  0.1945E-02 -0.1024E+01 -0.9808E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.5097E+01  0.4801E+00  0.3844E+01  0.6651E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.5167E+01  0.4644E+00  0.3947E+01  0.6716E+01
 4 CENTRE THRUST (N)               0.5149E+02  0.6122E+01  0.3590E+02  0.6498E+02
 5 CENTRE TORQUE (Nm)              0.3576E+01  0.5009E+00  0.2631E+01  0.4645E+01
 6 SUCT. UPPER BENDING (Nm)        0.1818E+01  0.3953E+00  0.6942E+00  0.2987E+01
 7 SUCT. LOWER BENDING (Nm)         0.1443E+01  0.2636E+00  0.5307E+00  0.2134E+01
 8 SUCT. TORSION (Nm)              -0.8233E-01  0.1951E+00 -0.5658E+00  0.4102E+00
 9 TOW FORCE (N)                   -0.2329E+02  0.1034E+02 -0.4699E+02  0.3646E+01
10 PORT SHAFT SPEED (RPS)          -0.4899E-01  0.1867E-02 -0.7397E-01 -0.3520E-01
11 CENTRE SHAFT SPEED (RPS)         0.4977E+01  0.1507E-01  0.4935E+01  0.5013E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.2267E-02  0.1934E-02 -0.4416E-01  0.8375E-02
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.4613E+01  0.1520E+01 -0.8504E+01  0.3146E-01
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.4856E+01  0.1663E+01 -0.8965E+01  0.3601E+00
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.5411E+01  0.1861E+01 -0.1015E+02  0.3224E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.5105E+01  0.4519E+00  0.3866E+01  0.6537E+01


GROUP NO.   2     TOTAL NO. OF SAMPLES =    4718     27-APR-1988 16:23:02

T1 =    79.0000 SEC.      T2 =    94.3400 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs = 0,BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.9948E+00  0.3137E-02 -0.1028E+01 -0.9848E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.2605E+01  0.2354E+00  0.1219E+01  0.4468E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     0.2737E+01  0.2181E+00  0.1585E+01  0.3512E+01
 4 CENTRE THRUST (N)                0.1897E+02  0.4259E+01  0.9676E+01  0.2865E+02
 5 CENTRE TORQUE (Nm)               0.1611E+01  0.4081E+00  0.7036E+00  0.2631E+01
 6 SUCT. UPPER BENDING (Nm)         0.1124E+01  0.1947E+00  0.4415E+00  0.1868E+01
 7 SUCT. LOWER BENDING (Nm)         0.8939E+00  0.1461E+00  0.2665E+00  0.1552E+01
 8 SUCT. TORSION (Nm)              -0.2244E+00  0.1337E+00 -0.1002E+01  0.8725E+00
 9 TOW FORCE (N)                   -0.9329E+01  0.6065E+01 -0.2200E+02  0.5384E+01
10 PORT SHAFT SPEED (RPS)          -0.4903E-01  0.1412E-02 -0.6489E-01 -0.3355E-01
11 CENTRE SHAFT SPEED (RPS)         0.3163E+01  0.8855E-02  0.3124E+01  0.3200E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.2377E-02  0.2481E-02 -0.4149E-01  0.1372E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.3172E+00  0.5965E+00 -0.2306E+01  0.1200E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.2505E+00  0.6707E+00 -0.2550E+01  0.1517E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.3089E+00  0.7439E+00 -0.2859E+01  0.2074E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.2686E+01  0.2280E+00  0.2086E+01  0.4478E+01


GROUP NO.   3     TOTAL NO. OF SAMPLES =    4483     27-APR-1988 16:32:19

T1 =    21.0000 SEC.      T2 =    34.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
REPEAT, Vs=0, BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM     MAXIMUM
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  1 CARRIAGE SPEED (M/S)             -0.1135E+01  0.4139E-02 -0.1181E+01 -0.1118E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1889E+01  0.4237E+00  0.2837E+00  0.2857E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)      0.1908E+01  0.4031E+00  0.9330E+00  0.2888E+01
  4 CENTRE THRUST (N)                 0.2151E+02  0.4462E+01  0.1175E+02  0.3196E+02
  5 CENTRE TORQUE (Nm)               -0.1910E+01  0.4388E+00 -0.2947E+01 -0.9227E+00
  6 SUCT. UPPER BENDING (Nm)          0.1731E+00  0.2801E+00 -0.5334E+00  0.1073E+01
  7 SUCT. LOWER BENDING (Nm)         -0.9214E-01  0.1940E+00 -0.8433E+00  0.7773E+00
  8 SUCT. TORSION (Nm)                0.2015E+00  0.2174E+00 -0.5915E+00  0.1669E+01
  9 TOW FORCE (N)                    -0.1016E+02  0.1128E+02 -0.4003E+02  0.1799E+02
 10 PORT SHAFT SPEED (RPS)           -0.4882E-01  0.1653E-02 -0.6324E-01 -0.3108E-01
 11 CENTRE SHAFT SPEED (RPS)          0.3349E+01  0.1034E-01  0.3298E+01  0.3415E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.2208E-02  0.1868E-02 -0.3793E-01  0.1194E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.1605E+01  0.1248E+01 -0.2546E+01  0.4679E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.1713E+01  0.1373E+01 -0.1762E+01  0.5915E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.2052E+01  0.1517E+01 -0.1037E+01  0.5575E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1861E+01  0.4059E+00  0.7513E+00  0.4395E+01



GROUP NO.   3     TOTAL NO. OF SAMPLES =     4483     27-APR-1988 16:32:19

T1 =   44.0000 SEC.      T2 =   55.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
REPEAT, Vs=0, BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)             -0.1145E+01  0.4979E-02 -0.1178E+01 -0.1129E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.3834E+01  0.4226E+00  0.2779E+01  0.4910E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)      0.3819E+01  0.4178E+00  0.2182E+01  0.4897E+01
  4 CENTRE THRUST (N)                 0.4874E+02  0.5543E+01  0.3494E+02  0.6124E+02
  5 CENTRE TORQUE (Nm)               -0.2856E+00  0.5530E+00 -0.1546E+01  0.8490E+00
  6 SUCT. UPPER BENDING (Nm)          0.6616E+00  0.3486E+00 -0.3890E+00  0.1543E+01
  7 SUCT. LOWER BENDING (Nm)          0.2874E+00  0.2407E+00 -0.7904E+00  0.1323E+01
  8 SUCT. TORSION (Nm)                0.3160E+00  0.1876E+00 -0.4374E+00  0.7698E+00
  9 TOW FORCE (N)                    -0.2214E+02  0.6042E+01 -0.3808E+02 -0.9178E+00
 10 PORT SHAFT SPEED (RPS)           -0.4898E-01  0.1160E-02 -0.6324E-01 -0.3768E-01
 11 CENTRE SHAFT SPEED (RPS)          0.4844E+01  0.1620E-01  0.4807E+01  0.4884E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.2194E-02  0.1629E-02 -0.2546E-01  0.8375E-02
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.4770E+01  0.1317E+01  0.1102E+01  0.8079E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.5066E+01  0.1436E+01  0.4812E+00  0.8649E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.5809E+01  0.1599E+01  0.1215E+01  0.9864E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.3755E+01  0.3990E+00  0.2782E+01  0.4757E+01



GROUP NO.   3     TOTAL NO. OF SAMPLES =     4483     27-APR-1988 16:32:19

T1 =   60.0000 SEC.      T2 =   70.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
REPEAT, Vs=0, BOLLARD CENT. ONLY, S.D FWD/MID
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CH DESCRIPTION                           AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1156E+01  0.3629E-02  -0.1195E+01  -0.1145E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        0.5467E+01  0.5218E+00   0.4156E+01   0.7508E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.5427E+01  0.5219E+00   0.4056E+01   0.6879E+01
 4 CENTRE THRUST (N)                   0.6803E+02  0.7427E+01   0.4966E+02   0.8623E+02
 5 CENTRE TORQUE (Nm)                  0.1193E+01  0.5902E+00  -0.1441E+00   0.2361E+01
 6 SUCT. UPPER BENDING (Nm)            0.1227E+01  0.7028E+00  -0.9848E+00   0.3493E+01
 7 SUCT. LOWER BENDING (Nm)            0.7578E+00  0.5032E+00  -0.7376E+00   0.2010E+01
 8 SUCT. TORSION (Nm)                  0.3685E+00  0.2423E+00  -0.8997E+00   0.1206E+01
 9 TOW FORCE (N)                      -0.3150E+02  0.1126E+02  -0.5764E+02   0.1473E+01
10 PORT SHAFT SPEED (RPS)             -0.4899E-01  0.1249E-02  -0.5500E-01  -0.3108E-01
11 CENTRE SHAFT SPEED (RPS)            0.5715E+01  0.2059E-01   0.5652E+01   0.5760E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.2152E-02  0.1923E-02  -0.2813E-01   0.1461E-01
13 NOZZLE BN [#1 GAUGE] (Nm)           0.7363E+01  0.1456E+01   0.3475E+01   0.1151E+02
14 NOZZLE BN [#2 GAUGE] (Nm)           0.7791E+01  0.1601E+01   0.3601E+01   0.1223E+02
15 NOZZLE BN [#3 GAUGE] (Nm)           0.8818E+01  0.1778E+01   0.4145E+01   0.1380E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)        0.5350E+01  0.5226E+00   0.3894E+01   0.6843E+01



GROUP NO.   3     TOTAL NO. OF SAMPLES =     4483      27-APR-1988 16:32:19

T1 =   76.0000 SEC.      T2 =   87.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
REPEAT, Vs=0, BOLLARD CENT. ONLY, S.D FWD/MID


CH DESCRIPTION                           AVERAGE         RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1163E+01  0.3473E-02  -0.1179E+01  -0.1155E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)        0.9046E+01  0.8547E+00   0.7093E+01   0.1151E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.9014E+01  0.8482E+00   0.7042E+01   0.1141E+02
 4 CENTRE THRUST (N)                   0.1052E+03  0.1187E+02   0.7381E+02   0.1342E+03
 5 CENTRE TORQUE (Nm)                  0.3702E+01  0.7309E+00   0.1832E+01   0.5202E+01
 6 SUCT. UPPER BENDING (Nm)            0.2769E+01  0.1481E+01  -0.6418E+00   0.6219E+01
 7 SUCT. LOWER BENDING (Nm)            0.1820E+01  0.9852E+00  -0.5060E-01   0.3913E+01
 8 SUCT. TORSION (Nm)                  0.2379E+00  0.4497E+00  -0.1054E+01   0.1900E+01
 9 TOW FORCE (N)                      -0.4488E+02  0.1046E+02  -0.7285E+02  -0.2547E+02
10 PORT SHAFT SPEED (RPS)             -0.4922E-01  0.1553E-02  -0.6407E-01  -0.3603E-01
11 CENTRE SHAFT SPEED (RPS)            0.6975E+01  0.2796E-01   0.6916E+01   0.7036E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.2191E-02  0.1340E-02  -0.1923E-01   0.7485E-02
13 NOZZLE BN [#1 GAUGE] (Nm)           0.1036E+02  0.2146E+01   0.5383E+01   0.1669E+02
14 NOZZLE BN [#2 GAUGE] (Nm)           0.1103E+02  0.2335E+01   0.5845E+01   0.1780E+02
15 NOZZLE BN [#3 GAUGE] (Nm)           0.1259E+02  0.2587E+01   0.6862E+01   0.2016E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)        0.8917E+01  0.8432E+00   0.6870E+01   0.1135E+02
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GROUP NO.   4     TOTAL NO. OF SAMPLES =    3703     27-APR-1988 16:50:29

T1 =   10.0000 SEC.      T2 =   12.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ALL SHAFTS, S.D FWD/MID


CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1565E+01  0.1804E-02 -0.1577E+01 -0.1562E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.4460E+01  0.4717E+00  0.3402E+01  0.5793E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.4450E+01  0.4550E+00  0.3512E+01  0.5685E+01
 4 CENTRE THRUST (N)                     0.2362E+02  0.4566E+01  0.1417E+02  0.3224E+02
 5 CENTRE TORQUE (Nm)                   -0.1431E+01  0.4079E+00 -0.2175E+01 -0.4279E+00
 6 SUCT. UPPER BENDING (Nm)              0.1961E+01  0.3546E+00  0.9109E+00  0.2861E+01
 7 SUCT. LOWER BENDING (Nm)              0.3573E+00  0.2959E+00 -0.1284E+01  0.1042E+01
 8 SUCT. TORSION (Nm)                    0.2876E+00  0.1776E+00  0.2494E-01  0.1515E+01
 9 TOW FORCE (N)                        -0.6465E+02  0.5311E+01 -0.7372E+02 -0.4981E+02
10 PORT SHAFT SPEED (RPS)                0.4123E+01  0.1755E-02  0.4114E+01  0.4132E+01
11 CENTRE SHAFT SPEED (RPS)              0.3204E+01  0.1013E-01  0.3183E+01  0.3241E+01
12 STRBRD. SHAFT SPEED (RPS)             0.3989E+01  0.4242E-02  0.3975E+01  0.4003E+01
13 NOZZLE BN [#1 GAUGE] (Nm)             0.4882E+01  0.1023E+01  0.2519E+01  0.9709E+01
14 NOZZLE BN [#2 GAUGE] (Nm)             0.5210E+01  0.9187E+00  0.2234E+01  0.7703E+01
15 NOZZLE BN [#3 GAUGE] (Nm)             0.6101E+01  0.1034E+01  0.3145E+01  0.9006E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)          0.4385E+01  0.4833E+00  0.2504E+01  0.5452E+01
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GROUP NO.   4     TOTAL NO. OF SAMPLES =    3703     27-APR-1988 16:50:29

T1 =   22.0000 SEC.      T2 =   32.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ALL SHAFTS, S.D FWD/MID


CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1747E+01  0.7273E-02 -0.1767E+01 -0.1731E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.8788E+01  0.8830E+00  0.5611E+01  0.1083E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.8737E+01  0.8801E+00  0.6798E+01  0.1155E+02
 4 CENTRE THRUST (N)                     0.5500E+02  0.7056E+01  0.3641E+02  0.7397E+02
 5 CENTRE TORQUE (Nm)                    0.4827E+00  0.4612E+00 -0.5006E+00  0.1545E+01
 6 SUCT. UPPER BENDING (Nm)              0.3739E+01  0.6920E+00  0.1976E+01  0.5641E+01
 7 SUCT. LOWER BENDING (Nm)              0.1878E+01  0.5360E+00 -0.1387E+00  0.3508E+01
 8 SUCT. TORSION (Nm)                    0.4829E+00  0.2548E+00 -0.1054E+01  0.1900E+01
 9 TOW FORCE (N)                        -0.1134E+03  0.6607E+01 -0.1294E+03 -0.9632E+02
10 PORT SHAFT SPEED (RPS)                0.5396E+01  0.3603E-02  0.5363E+01  0.5425E+01
11 CENTRE SHAFT SPEED (RPS)              0.4896E+01  0.1422E-01  0.4807E+01  0.4937E+01
12 STRBRD. SHAFT SPEED (RPS)             0.5238E+01  0.9004E-02  0.5201E+01  0.5264E+01
13 NOZZLE BN [#1 GAUGE] (Nm)             0.1141E+02  0.1386E+01  0.7442E+01  0.1555E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.1230E+02  0.1525E+01  0.7983E+01  0.1794E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.1410E+02  0.1690E+01  0.9221E+01  0.1926E+02
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16 NOZZLE TORSION [ #1 Gg] (Nm)   0.8647E+01  0.8588E+00  0.6704E+01  0.1124E+02


GROUP NO.   4     TOTAL NO. OF SAMPLES =    3703     27-APR-1988 16:50:29

T1 =   42.0000 SEC.     T2 =   52.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ALL SHAFTS, S.D FWD/MID


CH DESCRIPTION                       AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1971E+01  0.8183E-02 -0.1994E+01 -0.1939E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.1501E+02  0.1544E+01  0.1109E+02  0.1876E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.1491E+02  0.1581E+01  0.1087E+02  0.2097E+02
 4 CENTRE THRUST (N)               0.7976E+02  0.9787E+01  0.5734E+02  0.1058E+03
 5 CENTRE TORQUE (Nm)              0.1873E+01  0.5207E+00  0.3991E+00  0.3057E+01
 6 SUCT. UPPER BENDING (Nm)        0.7041E+01  0.2140E+01  0.1958E+01  0.1216E+02
 7 SUCT. LOWER BENDING (Nm)        0.4611E+01  0.1639E+01  0.7421E+00  0.8211E+01
 8 SUCT. TORSION (Nm)              0.6889E+00  0.7095E+00 -0.1182E+01  0.3056E+01
 9 TOW FORCE (N)                  -0.1985E+03  0.7840E+01 -0.2158E+03 -0.1817E+03
10 PORT SHAFT SPEED (RPS)          0.6996E+01  0.4544E-02  0.6964E+01  0.7011E+01
11 CENTRE SHAFT SPEED (RPS)        0.5759E+01  0.1630E-01  0.5705E+01  0.5816E+01
12 STRBRD. SHAFT SPEED (RPS)       0.7224E+01  0.1361E-01  0.7193E+01  0.7256E+01
13 NOZZLE BN [#1 GAUGE] (Nm)       0.1956E+02  0.2047E+01  0.1346E+02  0.2540E+02
14 NOZZLE BN [#2 GAUGE] (Nm)       0.2098E+02  0.2123E+01  0.1468E+02  0.2712E+02
15 NOZZLE BN [#3 GAUGE] (Nm)       0.2393E+02  0.2357E+01  0.1712E+02  0.3070E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.1472E+02  0.1548E+01  0.1088E+02  0.1850E+02


GROUP NO.   4     TOTAL NO. OF SAMPLES =    3703     27-APR-1988 16:50:29

T1 =   61.0000 SEC.     T2 =   69.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ALL SHAFTS, S.D FWD/MID


CH DESCRIPTION                       AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.2181E+01  0.8993E-02 -0.2210E+01 -0.2151E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.2265E+02  0.2083E+01  0.1783E+02  0.2786E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.2247E+02  0.2123E+01  0.1763E+02  0.2781E+02
 4 CENTRE THRUST (N)               0.1182E+03  0.1347E+02  0.8328E+02  0.1553E+03
 5 CENTRE TORQUE (Nm)              0.3982E+01  0.6500E+00  0.2039E+01  0.3555E+01
 6 SUCT. UPPER BENDING (Nm)        0.1146E+02  0.2392E+01  0.4522E+01  0.1776E+02
 7 SUCT. LOWER BENDING (Nm)        0.8039E+01  0.1802E+01  0.2926E+01  0.1314E+02
 8 SUCT. TORSION (Nm)              0.1044E+01  0.7264E+00 -0.1157E+01  0.3107E+01
 9 TOW FORCE (N)                  -0.3060E+03  0.7333E+01 -0.3238E+03 -0.2928E+03
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10 PORT SHAFT SPEED (RPS)          0.8546E+01  0.3664E-02  0.8520E+01  0.8566E+01
11 CENTRE SHAFT SPEED (RPS)        0.7056E+01  0.2275E-01  0.6984E+01  0.7125E+01
12 STRBRD. SHAFT SPEED (RPS)       0.9033E+01  0.9117E-02  0.9005E+01  0.9054E+01
13 NOZZLE BN [#1 GAUGE] (Nm)       0.3038E+02  0.3239E+01  0.2154E+02  0.4081E+02
14 NOZZLE BN [#2 GAUGE] (Nm)       0.3237E+02  0.3460E+01  0.2313E+02  0.4364E+02
15 NOZZLE BN [#3 GAUGE] (Nm)       0.3688E+02  0.3875E+01  0.2652E+02  0.4939E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.2215E+02  0.2130E+01  0.1708E+02  0.2748E+02
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GROUP NO.   5     TOTAL NO. OF SAMPLES =    2587     27-APR-1988 17:04:20

T1 =     1.0000 SEC.      T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT.ONLY, S.D FWD/MID


CH DESCRIPTION                      AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1027E+01  0.6945E-02 -0.1045E+01 -0.1012E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.2265E+01  0.3104E+00  0.1427E+01  0.3038E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.2347E+01  0.3037E+00  0.1558E+01  0.3132E+01
 4 CENTRE THRUST (N)               0.1754E+02  0.4747E+01  0.6215E+01  0.2810E+02
 5 CENTRE TORQUE (Nm)             -0.1708E+01  0.4420E+00 -0.2694E+01 -0.7082E+00
 6 SUCT. UPPER BENDING (Nm)        0.1466E+01  0.3271E+00  0.2970E+00  0.2283E+01
 7 SUCT. LOWER BENDING (Nm)        0.1086E+01  0.1871E+00  0.5659E+00  0.1764E+01
 8 SUCT. TORSION (Nm)             -0.9323E-01  0.1395E+00 -0.7970E+00  0.2561E+00
 9 TOW FORCE (N)                  -0.7154E+00  0.2210E+02 -0.5199E+02  0.5167E+02
10 PORT SHAFT SPEED (RPS)         -0.4945E-01  0.1123E-02 -0.6159E-01 -0.3933E-01
11 CENTRE SHAFT SPEED (RPS)        0.3178E+01  0.8849E-02  0.3119E+01  0.3204E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.2160E-02  0.1410E-02 -0.1478E-01  0.9266E-02
13 NOZZLE BN [#1 GAUGE] (Nm)       0.2389E+01  0.8317E+00  0.3936E+00  0.5529E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       0.2398E+01  0.9089E+00  0.9562E-01  0.4863E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       0.2569E+01  0.9965E+00  0.1780E+00  0.5253E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.2256E+01  0.3020E+00  0.1474E+01  0.3116E+01
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GROUP NO.   5     TOTAL NO. OF SAMPLES =    2587     27-APR-1988 17:04:20

T1 =    18.0000 SEC.      T2 =   25.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT.ONLY, S.D FWD/MID


CH DESCRIPTION                      AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1001E+01  0.5873E-02 -0.1031E+01 -0.9942E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.4342E+01  0.4508E+00  0.3116E+01  0.5559E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.4357E+01  0.4424E+00  0.3241E+01  0.5549E+01
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  4 CENTRE THRUST (N)                    0.4709E+02  0.6763E+01  0.3271E+02  0.6247E+02
  5 CENTRE TORQUE (Nm)                   0.2581E-01  0.5346E+00 -0.1172E+01  0.1202E+01
  6 SUCT. UPPER BENDING (Nm)             0.2077E+01  0.4809E+00  0.8206E+00  0.3276E+01
  7 SUCT. LOWER BENDING (Nm)             0.1504E+01  0.3028E+00  0.7597E+00  0.2979E+01
  8 SUCT. TORSION (Nm)                   0.6906E-01  0.2011E+00 -0.8483E+00  0.1001E+01
  9 TOW FORCE (N)                       -0.1078E+02  0.6537E+01 -0.2482E+02  0.1690E+01
 10 PORT SHAFT SPEED (RPS)              -0.4996E-01  0.2107E-02 -0.6902E-01 -0.2860E-01
 11 CENTRE SHAFT SPEED (RPS)             0.4856E+01  0.1420E-01  0.4823E+01  0.4898E+01
 12 STRBRD. SHAFT SPEED (RPS)           -0.2280E-02  0.2136E-02 -0.3081E-01  0.9266E-02
 13 NOZZLE BN [#1 GAUGE] (Nm)            0.6090E+01  0.1290E+01  0.2802E+01  0.9425E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)            0.6368E+01  0.1417E+01  0.2655E+01  0.1002E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)            0.7065E+01  0.1548E+01  0.3037E+01  0.1108E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)         0.4282E+01  0.4347E+00  0.3171E+01  0.5508E+01


GROUP NO.   5     TOTAL NO. OF SAMPLES =     2587     27-APR-1988 17:04:20

T1 =   32.0000 SEC.      T2 =   43.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT.ONLY, S.D FWD/MID


CH DESCRIPTION                           AVERAGE       RMS       MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)                -0.9857E+00  0.6734E-02 -0.1006E+01 -0.9634E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)         0.6066E+01  0.4652E+00  0.4572E+01  0.7196E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)         0.6045E+01  0.4697E+00  0.4517E+01  0.7368E+01
  4 CENTRE THRUST (N)                    0.6713E+02  0.7870E+01  0.4676E+02  0.8802E+02
  5 CENTRE TORQUE (Nm)                   0.1208E+01  0.5991E+00 -0.2376E+00  0.2690E+01
  6 SUCT. UPPER BENDING (Nm)             0.2593E+01  0.6202E+00  0.5317E+00  0.4504E+01
  7 SUCT. LOWER BENDING (Nm)             0.1823E+01  0.4125E+00  0.7597E+00  0.3014E+01
  8 SUCT. TORSION (Nm)                   0.8008E-01  0.2067E+00 -0.7199E+00  0.5900E+00
  9 TOW FORCE (N)                       -0.1790E+02  0.1444E+02 -0.5155E+02  0.6906E+01
 10 PORT SHAFT SPEED (RPS)              -0.5011E-01  0.1067E-02 -0.5665E-01 -0.3768E-01
 11 CENTRE SHAFT SPEED (RPS)             0.5708E+01  0.1896E-01  0.5625E+01  0.5747E+01
 12 STRBRD. SHAFT SPEED (RPS)           -0.2095E-02  0.1772E-02 -0.3348E-01  0.1105E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)            0.8615E+01  0.1374E+01  0.4679E+01  0.1293E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)            0.8940E+01  0.1523E+01  0.4092E+01  0.1349E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)            0.1011E+02  0.1699E+01  0.5075E+01  0.1512E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)         0.5964E+01  0.4700E+00  0.4172E+01  0.7093E+01


GROUP NO.   5     TOTAL NO. OF SAMPLES =     2587     27-APR-1988 17:04:20

T1 =   47.0000 SEC.      T2 =   50.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT.ONLY, S.D FWD/MID
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CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)             -0.9796E+00  0.5433E-02 -0.9902E+00 -0.9630E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.9057E+01  0.9860E+00  0.6443E+01  0.1112E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.8998E+01  0.9733E+00  0.6418E+01  0.1114E+02
 4 CENTRE THRUST (N)                 0.1026E+03  0.1157E+02  0.7417E+02  0.1301E+03
 5 CENTRE TORQUE (Nm)                0.3307E+01  0.7131E+00  0.1704E+01  0.4808E+01
 6 SUCT. UPPER BENDING (Nm)          0.3532E+01  0.1592E+01 -0.4598E-01  0.6490E+01
 7 SUCT. LOWER BENDING (Nm)          0.2647E+01  0.1055E+01  0.7773E+00  0.4529E+01
 8 SUCT. TORSION (Nm)                0.1702E+00  0.5141E+00 -0.1670E+01  0.1361E+01
 9 TOW FORCE (N)                    -0.2900E+02  0.8341E+01 -0.4395E+02 -0.1439E+02
10 PORT SHAFT SPEED (RPS)           -0.5033E-01  0.1591E-02 -0.6819E-01 -0.4757E-01
11 CENTRE SHAFT SPEED (RPS)          0.6966E+01  0.2869E-01  0.6903E+01  0.7047E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2316E-02  0.9749E-03 -0.9434E-02 -0.5295E-03
13 NOZZLE BN [#1 GAUGE] (Nm)         0.1310E+02  0.2499E+01  0.7548E+01  0.2079E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1371E+02  0.2699E+01  0.7808E+01  0.2208E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         0.1540E+02  0.3002E+01  0.8899E+01  0.2445E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.8883E+01  0.9539E+00  0.6370E+01  0.1099E+02



GROUP NO.   6     TOTAL NO. OF SAMPLES =     3179     27-APR-1988 17:10:32

T1 =     1.0000 SEC.     T2 =    9.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT. ONLY, S.D. FWD/MID


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)              0.2659E+00  0.2767E-03  0.2639E+00  0.2681E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.2103E+01  0.3252E+00  0.1193E+01  0.2908E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.2121E+01  0.3146E+00  0.1367E+01  0.2942E+01
 4 CENTRE THRUST (N)                 0.1588E+02  0.4558E+01  0.6016E+01  0.2659E+02
 5 CENTRE TORQUE (Nm)               -0.1681E+01  0.4204E+00 -0.2736E+01 -0.6563E+00
 6 SUCT. UPPER BENDING (Nm)          0.1219E+01  0.3335E+00  0.3151E+00  0.2337E+01
 7 SUCT. LOWER BENDING (Nm)          0.7258E+00  0.2191E+00 -0.8583E-01  0.1464E+01
 8 SUCT. TORSION (Nm)                0.2641E-01  0.1640E+00 -0.1311E+01  0.4102E+00
 9 TOW FORCE (N)                    -0.1176E+01  0.6676E+01 -0.1591E+02  0.1234E+02
10 PORT SHAFT SPEED (RPS)           -0.5000E-01  0.1595E-02 -0.6077E-01 -0.3273E-01
11 CENTRE SHAFT SPEED (RPS)          0.3179E+01  0.8553E-02  0.3158E+01  0.3212E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2151E-02  0.1391E-02 -0.1300E-01  0.7485E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.2390E+01  0.8653E+00  0.4290E+00  0.4467E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.2435E+01  0.9506E+00  0.9562E-01  0.4828E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2912E+01  0.1050E+01  0.6426E+00  0.5539E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.2085E+01  0.3426E+00  0.1113E+01  0.3866E+01



GROUP NO.   6     TOTAL NO. OF SAMPLES =     3179     27-APR-1988 17:10:32

T1 =    15.0000 SEC.     T2 =   25.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT. ONLY, S.D. FWD/MID


CH DESCRIPTION                             AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                  0.2659E+00  0.3403E-03  0.2640E+00  0.2702E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.4454E+01  0.4435E+00  0.3090E+01  0.5767E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.4401E+01  0.4456E+00  0.3078E+01  0.5630E+01
 4 CENTRE THRUST (N)                     0.4989E+02  0.6768E+01  0.3403E+02  0.6518E+02
 5 CENTRE TORQUE (Nm)                    0.3524E+00  0.5251E+00 -0.9954E+00  0.1524E+01
 6 SUCT. UPPER BENDING (Nm)              0.1793E+01  0.5225E+00  0.1165E+00  0.3168E+01
 7 SUCT. LOWER BENDING (Nm)              0.1207E+01  0.3641E+00  0.1256E+00  0.2098E+01
 8 SUCT. TORSION (Nm)                    0.2369E+00  0.2150E+00 -0.9254E+00  0.1283E+01
 9 TOW FORCE (N)                        -0.1333E+02  0.1472E+02 -0.4916E+02  0.2386E+02
10 PORT SHAFT SPEED (RPS)               -0.5029E-01  0.1435E-02 -0.6489E-01 -0.3768E-01
11 CENTRE SHAFT SPEED (RPS)              0.5062E+01  0.1703E-01  0.5010E+01  0.5112E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.2088E-02  0.1850E-02 -0.2012E-01  0.1906E-01
13 NOZZLE BN [#1 GAUGE] (Nm)             0.6696E+01  0.1165E+01  0.3298E+01  0.1130E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.7087E+01  0.1278E+01  0.3356E+01  0.1212E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.8053E+01  0.1407E+01  0.3931E+01  0.1333E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)          0.4348E+01  0.4279E+00  0.3116E+01  0.5563E+01




GROUP NO.   6    TOTAL NO. OF SAMPLES =    3179     27-APR-1988 17:10:32

T1 =   31.0000 SEC.      T2 =   41.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT. ONLY, S.D. FWD/MID


CH DESCRIPTION                             AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                  0.2659E+00  0.2425E-03  0.2640E+00  0.2666E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.5940E+01  0.5385E+00  0.4286E+01  0.7222E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.5865E+01  0.5401E+00  0.4191E+01  0.7151E+01
 4 CENTRE THRUST (N)                     0.6645E+02  0.7959E+01  0.4724E+02  0.8507E+02
 5 CENTRE TORQUE (Nm)                    0.1303E+01  0.6029E+00 -0.1545E+00  0.2524E+01
 6 SUCT. UPPER BENDING (Nm)              0.2356E+01  0.7465E+00  0.3151E+00  0.4179E+01
 7 SUCT. LOWER BENDING (Nm)              0.1545E+01  0.5332E+00 -0.2620E+00  0.2785E+01
 8 SUCT. TORSION (Nm)                    0.2131E+00  0.2524E+00 -0.1311E+01  0.9496E+00
 9 TOW FORCE (N)                        -0.2040E+02  0.2170E+02 -0.6742E+02  0.3211E+02
10 PORT SHAFT SPEED (RPS)               -0.5023E-01  0.1021E-02 -0.6489E-01 -0.4427E-01
11 CENTRE SHAFT SPEED (RPS)              0.5749E+01  0.2013E-01  0.5693E+01  0.5791E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.2150E-02  0.1858E-02 -0.2457E-01  0.2262E-01
13 NOZZLE BN [#1 GAUGE] (Nm)             0.8851E+01  0.1618E+01  0.4892E+01  0.1399E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.9278E+01  0.1796E+01  0.4828E+01  0.1468E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.1061E+02  0.2010E+01  0.5504E+01  0.1666E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)          0.5803E+01  0.5501E+00  0.3866E+01  0.7121E+01
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GROUP NO.   6     TOTAL NO. OF SAMPLES =     3179     27-APR-1988 17:10:32

T1 =    51.0000 SEC.     T2 =    61.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K, Vm=0.266 m/s, CENT. ONLY, S.D. FWD/MID


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              0.2659E+00  0.2630E-03  0.2636E+00  0.2675E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.9382E+01  0.1128E+01  0.6677E+01  0.1232E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.9291E+01  0.1115E+01  0.6635E+01  0.1239E+02
 4 CENTRE THRUST (N)                 0.1043E+03  0.1168E+02  0.7612E+02  0.1306E+03
 5 CENTRE TORQUE (Nm)                0.3461E+01  0.7266E+00  0.1749E+01  0.4901E+01
 6 SUCT. UPPER BENDING (Nm)          0.3429E+01  0.2029E+01 -0.1021E+01  0.7392E+01
 7 SUCT. LOWER BENDING (Nm)          0.2395E+01  0.1442E+01 -0.3853E+00  0.4899E+01
 8 SUCT. TORSION (Nm)                0.2635E+00  0.6223E+00 -0.6685E+00  0.1926E+01
 9 TOW FORCE (N)                    -0.3290E+02  0.1528E+02 -0.6524E+02 -0.3308E+01
10 PORT SHAFT SPEED (RPS)           -0.5012E-01  0.1710E-02 -0.6077E-01 -0.2943E-01
11 CENTRE SHAFT SPEED (RPS)          0.7058E+01  0.2726E-01  0.6972E+01  0.7116E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2086E-02  0.1048E-02 -0.1567E-01  0.6594E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.1278E+02  0.2586E+01  0.6521E+01  0.2051E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1357E+02  0.2780E+01  0.6721E+01  0.2130E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         0.1546E+02  0.3097E+01  0.7898E+01  0.2405E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.9229E+01  0.1099E+01  0.6648E+01  0.1210E+02
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GROUP NO.   7     TOTAL NO. OF SAMPLES =     3836     27-APR-1988 17:17:32

T1 =     1.0000 SEC.     T2 =    13.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=5K, Vm=0.664 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              0.6662E+00  0.2819E-02  0.6402E+00  0.6681E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.5192E+01  0.4947E+00  0.4026E+01  0.7067E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.5156E+01  0.4886E+00  0.3730E+01  0.6988E+01
 4 CENTRE THRUST (N)                 0.1054E+02  0.4866E+01 -0.1305E+01  0.2121E+02
 5 CENTRE TORQUE (Nm)               -0.1952E+01  0.4707E+00 -0.3148E+01 -0.8362E+00
 6 SUCT. UPPER BENDING (Nm)          0.5807E+01  0.3784E+00  0.4413E+01  0.7031E+01
 7 SUCT. LOWER BENDING (Nm)          0.4212E+01  0.2073E+00  0.3332E+01  0.5093E+01
 8 SUCT. TORSION (Nm)               -0.1153E+01  0.1579E+00 -0.1901E+01  0.3588E+00
 9 TOW FORCE (N)                     0.4487E+02  0.2939E+02 -0.2721E+02  0.1086E+03
10 PORT SHAFT SPEED (RPS)           -0.4953E-01  0.1281E-02 -0.5995E-01 -0.3520E-01
11 CENTRE SHAFT SPEED (RPS)          0.3189E+01  0.9007E-02  0.3153E+01  0.3210E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2032E-02  0.2323E-02 -0.3793E-01  0.1817E-01
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13 NOZZLE BN [#1 GAUGE] (Nm)       0.7274E+01  0.1132E+01  0.4502E+01  0.1031E+02
14 NOZZLE BN [#2 GAUGE] (Nm)       0.7556E+01  0.1270E+01  0.4478E+01  0.1124E+02
15 NOZZLE BN [#3 GAUGE] (Nm)       0.8555E+01  0.1403E+01  0.5218E+01  0.1244E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.5106E+01  0.4916E+00  0.4033E+01  0.8094E+01


GROUP NO.   7     TOTAL NO. OF SAMPLES =     3836     27-APR-1988 17:17:32

T1 =   23.0000 SEC.      T2 =   33.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=5K, Vm=0.664 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                       AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.6673E+00  0.3423E-03  0.6650E+00  0.6687E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.7520E+01  0.4262E+00  0.6079E+01  0.8912E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.7408E+01  0.4289E+00  0.6010E+01  0.9024E+01
 4 CENTRE THRUST (N)               0.4492E+02  0.6086E+01  0.2750E+02  0.6064E+02
 5 CENTRE TORQUE (Nm)              0.1212E+00  0.5930E+00 -0.1383E+01  0.1243E+01
 6 SUCT. UPPER BENDING (Nm)        0.6449E+01  0.4617E+00  0.5117E+01  0.7970E+01
 7 SUCT. LOWER BENDING (Nm)        0.4773E+01  0.2748E+00  0.4089E+01  0.5586E+01
 8 SUCT. TORSION (Nm)             -0.1067E+01  0.1724E+00 -0.1670E+01 -0.2319E+00
 9 TOW FORCE (N)                   0.4355E+02  0.1089E+02  0.2081E+02  0.6884E+02
10 PORT SHAFT SPEED (RPS)         -0.5040E-01  0.2399E-02 -0.6819E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)        0.5010E+01  0.1660E-01  0.4971E+01  0.5067E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.2216E-02  0.1043E-02 -0.1211E-01  0.3032E-02
13 NOZZLE BN [#1 GAUGE] (Nm)       0.1204E+02  0.1178E+01  0.8611E+01  0.1530E+02
14 NOZZLE BN [#2 GAUGE] (Nm)       0.1255E+02  0.1283E+01  0.9035E+01  0.1615E+02
15 NOZZLE BN [#3 GAUGE] (Nm)       0.1420E+02  0.1407E+01  0.1008E+02  0.1851E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.7341E+01  0.4153E+00  0.6203E+01  0.8651E+01


GROUP NO.   7     TOTAL NO. OF SAMPLES =     3836     27-APR-1988 17:17:32

T1 =   41.0000 SEC.      T2 =   51.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=5K, Vm=0.664 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                       AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)            0.6677E+00  0.2729E-03  0.6668E+00  0.6685E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.8705E+01  0.4371E+00  0.7560E+01  0.9925E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.8551E+01  0.4415E+00  0.7422E+01  0.9703E+01
 4 CENTRE THRUST (N)               0.6394E+02  0.8073E+01  0.4238E+02  0.8475E+02
 5 CENTRE TORQUE (Nm)              0.1248E+01  0.6438E+00 -0.5213E+00  0.2655E+01
 6 SUCT. UPPER BENDING (Nm)        0.6532E+01  0.4434E+00  0.5352E+01  0.7753E+01
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  7 SUCT. LOWER BENDING (Nm)          0.4838E+01  0.2757E+00  0.4159E+01  0.5674E+01
  8 SUCT. TORSION (Nm)               -0.9599E+00  0.1724E+00 -0.1670E+01  0.1790E+00
  9 TOW FORCE (N)                     0.3369E+02  0.1325E+02  0.5167E+01  0.6341E+02
 10 PORT SHAFT SPEED (RPS)           -0.5063E-01  0.2276E-02 -0.6819E-01 -0.2366E-01
 11 CENTRE SHAFT SPEED (RPS)          0.5769E+01  0.2038E-01  0.5723E+01  0.5813E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.2136E-02  0.1755E-02 -0.2012E-01  0.1372E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.1419E+02  0.1325E+01  0.1035E+02  0.1793E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.1476E+02  0.1456E+01  0.1040E+02  0.1864E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.1672E+02  0.1610E+01  0.1204E+02  0.2102E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.8498E+01  0.4420E+00  0.7260E+01  0.1057E+02


GROUP NO.   7     TOTAL NO. OF SAMPLES =     3836     27-APR-1988 17:17:32

T1 =    64.0000 SEC.      T2 =    75.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=5K, Vm=0.664 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                         AVERAGE        RMS       MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)              0.6680E+00  0.2748E-03  0.6673E+00  0.6691E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1142E+02  0.6562E+00  0.9431E+01  0.1304E+02
  3 NOZZLE TORSION [ #3 Gg] (Nm)      0.1118E+02  0.6538E+00  0.9106E+01  0.1285E+02
  4 CENTRE THRUST (N)                 0.1057E+03  0.1185E+02  0.7540E+02  0.1381E+03
  5 CENTRE TORQUE (Nm)                0.3508E+01  0.7298E+00  0.1891E+01  0.5223E+01
  6 SUCT. UPPER BENDING (Nm)          0.7094E+01  0.9967E+00  0.4792E+01  0.9830E+01
  7 SUCT. LOWER BENDING (Nm)          0.5327E+01  0.5005E+00  0.4001E+01  0.6678E+01
  8 SUCT. TORSION (Nm)               -0.6712E+00  0.2739E+00 -0.1876E+01  0.1534E+00
  9 TOW FORCE (N)                     0.1635E+02  0.1281E+02 -0.1265E+02  0.4298E+02
 10 PORT SHAFT SPEED (RPS)           -0.5061E-01  0.1304E-02 -0.6407E-01 -0.3933E-01
 11 CENTRE SHAFT SPEED (RPS)          0.7116E+01  0.2779E-01  0.7050E+01  0.7187E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.2094E-02  0.1514E-02 -0.1834E-01  0.1283E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.1938E+02  0.1990E+01  0.1417E+02  0.2547E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.2029E+02  0.2188E+01  0.1454E+02  0.2677E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.2282E+02  0.2454E+01  0.1633E+02  0.3027E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1112E+02  0.6533E+00  0.8873E+01  0.1268E+02


GROUP NO.   8     TOTAL NO. OF SAMPLES =     1860     27-APR-1988 17:25:54

T1 =     1.0000 SEC.      T2 =     6.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=15K, Vm=1.992 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                         AVERAGE        RMS       MINIMUM     MAXIMUM
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  1 CARRIAGE SPEED (M/S)                0.2001E+01  0.3524E-02  0.1978E+01  0.2014E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)        0.2605E+02  0.1830E+01  0.2094E+02  0.3077E+02
  3 NOZZLE TORSION [ #3 Gg] (Nm)        0.2552E+02  0.1828E+01  0.2040E+02  0.3015E+02
  4 CENTRE THRUST (N)                  -0.3027E+02  0.6271E+01 -0.4324E+02 -0.1706E+02
  5 CENTRE TORQUE (Nm)                 -0.4322E+01  0.6173E+00 -0.6248E+01 -0.2881E+01
  6 SUCT. UPPER BENDING (Nm)            0.4881E+02  0.7452E+01  0.3565E+02  0.6349E+02
  7 SUCT. LOWER BENDING (Nm)            0.3922E+02  0.1082E+01  0.3641E+02  0.4253E+02
  8 SUCT. TORSION (Nm)                 -0.1318E+02  0.6475E+00 -0.1490E+02 -0.1148E+02
  9 TOW FORCE (N)                       0.4988E+03  0.8219E+02  0.3524E+03  0.8197E+03
 10 PORT SHAFT SPEED (RPS)              0.4366E+01  0.3426E-01  0.4298E+01  0.4466E+01
 11 CENTRE SHAFT SPEED (RPS)            0.3175E+01  0.1644E-01  0.3109E+01  0.3214E+01
 12 STRBRD. SHAFT SPEED (RPS)           0.2571E+01  0.6672E-01  0.2482E+01  0.2714E+01
 13 NOZZLE BN [#1 GAUGE] (Nm)           0.4580E+02  0.4076E+01  0.3599E+02  0.5674E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)           0.4773E+02  0.4454E+01  0.3676E+02  0.5983E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)           0.5269E+02  0.4912E+01  0.4100E+02  0.6548E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)        0.2521E+02  0.1818E+01  0.2019E+02  0.2993E+02



GROUP NO.   8     TOTAL NO. OF SAMPLES =     1860      27-APR-1988 17:25:54

T1 =    10.0000 SEC.      T2 =    16.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=15K, Vm=1.992 m/s, CENT. ONLY-VAR, S.D. FWD/MID


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)                0.2001E+01  0.2735E-02  0.1986E+01  0.2025E+01
  2 NOZZLE TORSION [ #2 Gg] (Nm)        0.3360E+02  0.9703E+00  0.3072E+02  0.3654E+02
  3 NOZZLE TORSION [ #3 Gg] (Nm)        0.3303E+02  0.9782E+00  0.3012E+02  0.3599E+02
  4 CENTRE THRUST (N)                   0.1725E+02  0.6787E+01  0.1640E+01  0.3176E+02
  5 CENTRE TORQUE (Nm)                 -0.1178E+01  0.6404E+00 -0.2736E+01  0.1396E+00
  6 SUCT. UPPER BENDING (Nm)            0.4532E+02  0.7852E+01  0.3066E+02  0.5793E+02
  7 SUCT. LOWER BENDING (Nm)            0.3665E+02  0.1034E+01  0.3375E+02  0.4046E+02
  8 SUCT. TORSION (Nm)                 -0.1081E+02  0.4515E+00 -0.1233E+02 -0.9607E+01
  9 TOW FORCE (N)                       0.4780E+03  0.1529E+02  0.4531E+03  0.5074E+03
 10 PORT SHAFT SPEED (RPS)              0.4381E+01  0.1789E-01  0.4334E+01  0.4419E+01
 11 CENTRE SHAFT SPEED (RPS)            0.5496E+01  0.1803E-01  0.5461E+01  0.5572E+01
 12 STRBRD. SHAFT SPEED (RPS)           0.2552E+01  0.2491E-01  0.2497E+01  0.2608E+01
 13 NOZZLE BN [#1 GAUGE] (Nm)           0.5412E+02  0.3425E+01  0.4665E+02  0.6315E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)           0.5627E+02  0.3820E+01  0.4802E+02  0.6611E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)           0.6224E+02  0.4201E+01  0.5315E+02  0.7320E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)        0.3290E+02  0.9769E+00  0.3010E+02  0.3580E+02



GROUP NO.   8     TOTAL NO. OF SAMPLES =     1860      27-APR-1988 17:25:54

T1 =    20.0000 SEC.      T2 =    35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=15K, Vm=1.992 m/s, CENT. ONLY-VAR, S.D. FWD/MID
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CH DESCRIPTION                        AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             0.2001E+01  0.1884E-02  0.1983E+01  0.2013E+01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.3781E+02  0.9835E+00  0.3461E+02  0.4085E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)     0.3713E+02  0.9998E+00  0.3390E+02  0.4020E+02
 4 CENTRE THRUST (N)                0.6993E+02  0.1315E+02  0.4170E+02  0.1001E+03
 5 CENTRE TORQUE (Nm)               0.1859E+01  0.6623E+00  0.2953E+00  0.3323E+01
 6 SUCT. UPPER BENDING (Nm)         0.4603E+02  0.7139E+01  0.3269E+02  0.5834E+02
 7 SUCT. LOWER BENDING (Nm)         0.3720E+02  0.7988E+00  0.3485E+02  0.3974E+02
 8 SUCT. TORSION (Nm)              -0.1027E+02  0.3528E+00 -0.1164E+02 -0.9170E+01
 9 TOW FORCE (N)                    0.4630E+03  0.1425E+02  0.4233E+03  0.4896E+03
10 PORT SHAFT SPEED (RPS)           0.4349E+01  0.2244E-01  0.4289E+01  0.4400E+01
11 CENTRE SHAFT SPEED (RPS)         0.7283E+01  0.2613E-01  0.7206E+01  0.7352E+01
12 STRBRD. SHAFT SPEED (RPS)        0.2508E+01  0.2886E-01  0.2444E+01  0.2585E+01
13 NOZZLE BN [#1 GAUGE] (Nm)        0.6111E+02  0.3640E+01  0.5115E+02  0.7098E+02
14 NOZZLE BN [#2 GAUGE] (Nm)        0.6374E+02  0.3943E+01  0.5314E+02  0.7414E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        0.7063E+02  0.4274E+01  0.5919E+02  0.8210E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.3709E+02  0.9888E+00  0.3382E+02  0.4005E+02



GROUP NO.   9     TOTAL NO. OF SAMPLES =     2306     27-APR-1988 17:33:05

T1 =    4.5000 SEC.     T2 =   25.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
ZERO LEVEL STATS CHECK


CH DESCRIPTION                        AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             0.1286E-02  0.1556E-02 -0.1797E-01  0.1901E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.6439E+00  0.1284E+00 -0.1509E+01  0.9334E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.6042E+00  0.1107E+00 -0.1619E+01  0.1150E+01
 4 CENTRE THRUST (N)               -0.5039E+01  0.4923E+01 -0.1384E+02  0.4663E+01
 5 CENTRE TORQUE (Nm)              -0.3058E+01  0.3472E+00 -0.3691E+01 -0.2220E+01
 6 SUCT. UPPER BENDING (Nm)         0.2299E+01  0.7449E-01  0.1741E+01  0.3041E+01
 7 SUCT. LOWER BENDING (Nm)         0.1278E+01  0.1429E+00  0.5836E+00  0.1834E+01
 8 SUCT. TORSION (Nm)               0.1218E+01  0.1055E+00 -0.5211E-01  0.2362E+01
 9 TOW FORCE (N)                    0.2189E+01  0.1055E+02 -0.2591E+02  0.3407E+02
10 PORT SHAFT SPEED (RPS)          -0.3605E-01  0.2405E-02 -0.6902E-01 -0.2118E-01
11 CENTRE SHAFT SPEED (RPS)         0.1620E+00  0.3671E-02  0.1162E+00  0.1992E+00
12 STRBRD. SHAFT SPEED (RPS)       -0.3729E-02  0.1938E-02 -0.2991E-01  0.1906E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.8490E+00  0.1715E+00 -0.4140E+01  0.7123E+00
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1299E+01  0.1616E+00 -0.2744E+01 -0.1147E+00
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.1437E+01  0.2097E+00 -0.5398E+01  0.3210E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.6246E+00  0.8888E-01 -0.1529E+01  0.5566E+00
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GROUP NO.  10     TOTAL NO. OF SAMPLES =     1982       27-APR-1988 17:47:47

T1 =     0.0000 SEC.     T2 =    35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
ASTERN ZERO STATS


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               0.1179E-02  0.1969E-02 -0.2644E-01  0.2524E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1862E+02  0.9362E-01 -0.2017E+02 -0.1682E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.1846E+02  0.1091E+00 -0.1984E+02 -0.1672E+02
 4 CENTRE THRUST (N)                 -0.7740E+01  0.6461E+01 -0.1913E+02  0.6573E+01
 5 CENTRE TORQUE (Nm)                -0.4421E+01  0.3525E+00 -0.5148E+01 -0.3684E+01
 6 SUCT. UPPER BENDING (Nm)           0.8178E+02  0.1116E+00  0.8044E+02  0.8307E+02
 7 SUCT. LOWER BENDING (Nm)           0.6596E+02  0.1701E+00  0.6456E+02  0.6698E+02
 8 SUCT. TORSION (Nm)                 0.5645E+02  0.1365E+00  0.5414E+02  0.5799E+02
 9 TOW FORCE (N)                      0.4024E+00  0.9332E+01 -0.2461E+02  0.2212E+02
10 PORT SHAFT SPEED (RPS)            -0.6922E-01  0.1514E-02 -0.8799E-01 -0.4922E-01
11 CENTRE SHAFT SPEED (RPS)          -0.3210E-01  0.4376E-02 -0.7356E-01  0.1625E-01
12 STRBRD. SHAFT SPEED (RPS)         -0.1801E-01  0.2072E-02 -0.4149E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.2124E+02  0.1817E+00 -0.2348E+02 -0.1831E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         -0.2298E+02  0.1648E+00 -0.2413E+02 -0.2101E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         -0.2611E+02  0.1459E+00 -0.2881E+02 -0.2473E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.1815E+02  0.1318E+00 -0.2017E+02 -0.1622E+02




GROUP NO.  11     TOTAL NO. OF SAMPLES =     1366       27-APR-1988 17:59:47

T1 =     4.0000 SEC.     T2 =    24.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
ASTERN ZERO STATS


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1846E+00  0.2794E-03 -0.1872E+00 -0.1816E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.5101E-02  0.1347E+00 -0.1645E+01  0.1994E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.3869E-02  0.1308E+00 -0.2228E+01  0.7047E+00
 4 CENTRE THRUST (N)                 -0.1081E+01  0.7354E+01 -0.1229E+02  0.1222E+02
 5 CENTRE TORQUE (Nm)                 0.2729E-01  0.3422E+00 -0.7178E+00  0.6490E+00
 6 SUCT. UPPER BENDING (Nm)          -0.1011E+00  0.9623E-01 -0.1229E+01  0.1100E+01
 7 SUCT. LOWER BENDING (Nm)          -0.1508E-01  0.1562E+00 -0.1085E+01  0.1434E+01
 8 SUCT. TORSION (Nm)                -0.5356E-01  0.1251E+00 -0.1829E+01  0.1330E+01
 9 TOW FORCE (N)                     -0.7118E-01  0.1718E+01 -0.1148E+02  0.5687E+01
10 PORT SHAFT SPEED (RPS)            -0.6958E-01  0.1618E-02 -0.9211E-01 -0.4840E-01
11 CENTRE SHAFT SPEED (RPS)          -0.3102E-01  0.5408E-02 -0.1075E+00  0.2302E-01
12 STRBRD. SHAFT SPEED (RPS)         -0.1697E-01  0.1952E-02 -0.4683E-01  0.5704E-02
13 NOZZLE BN [#1 GAUGE] (Nm)          0.9751E-01  0.1671E+00 -0.1395E+01  0.2253E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          0.5895E-01  0.2009E+00 -0.3135E+01  0.2368E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         -0.1351E-02  0.1586E+00 -0.7176E+00  0.2285E+01
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16 NOZZLE TORSION [ #1 Gg] (Nm)   0.9664E-02  0.1100E+00 -0.1565E+01  0.1050E+01



GROUP NO.  12     TOTAL NO. OF SAMPLES =    4185     27-APR-1988 18:02:37

T1 =    1.0000 SEC.      T2 =    9.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ASTERN, CENT. ONLY - VAR, S.D. AFT/MID


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1793E+00  0.2073E-03 -0.1828E+00 -0.1788E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.4018E+01  0.3611E+00 -0.5205E+01 -0.3178E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.4163E+01  0.3545E+00 -0.4916E+01 -0.3368E+01
 4 CENTRE THRUST (N)                -0.2632E+02  0.7523E+01 -0.3962E+02 -0.1261E+02
 5 CENTRE TORQUE (Nm)               -0.1177E+01  0.2916E+00 -0.2009E+01 -0.6036E+00
 6 SUCT. UPPER BENDING (Nm)          0.4163E+00  0.1989E+00 -0.2719E+00  0.9196E+00
 7 SUCT. LOWER BENDING (Nm)          0.1601E+00  0.1637E+00 -0.8560E+00  0.5356E+00
 8 SUCT. TORSION (Nm)               -0.1740E+00  0.1183E+00 -0.7504E+00  0.1125E+01
 9 TOW FORCE (N)                     0.1216E+02  0.1272E+01  0.8295E+01  0.1568E+02
10 PORT SHAFT SPEED (RPS)           -0.5068E-01  0.2393E-02 -0.7562E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)         -0.3258E+01  0.1137E-01 -0.3307E+01 -0.3227E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1895E-02  0.1328E-02 -0.1745E-01  0.6594E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.1670E+00  0.7485E+00 -0.1395E+01  0.1828E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.3079E-01  0.8278E+00 -0.1803E+01  0.1843E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.4413E+00  0.9467E+00 -0.3255E+01  0.1641E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.4092E+01  0.3440E+00 -0.5125E+01 -0.3345E+01



GROUP NO.  12     TOTAL NO. OF SAMPLES =    4185     27-APR-1988 18:02:37

T1 =   17.0000 SEC.      T2 =   24.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ASTERN, CENT. ONLY - VAR, S.D. AFT/MID


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1786E+00  0.1810E-03 -0.1810E+00 -0.1781E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.9194E+01  0.4757E+00 -0.1066E+02 -0.7570E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.9532E+01  0.4756E+00 -0.1081E+02 -0.7957E+01
 4 CENTRE THRUST (N)                -0.6008E+02  0.7452E+01 -0.7376E+02 -0.4384E+02
 5 CENTRE TORQUE (Nm)               -0.2944E+01  0.3266E+00 -0.3939E+01 -0.2060E+01
 6 SUCT. UPPER BENDING (Nm)          0.1421E+01  0.4878E+00  0.8915E-01  0.2508E+01
 7 SUCT. LOWER BENDING (Nm)          0.5969E+00  0.3574E+00 -0.5917E+00  0.1610E+01
 8 SUCT. TORSION (Nm)               -0.4333E+00  0.1612E+00 -0.8532E+00 -0.5578E-02
 9 TOW FORCE (N)                     0.2733E+02  0.1746E+01  0.2351E+02  0.3198E+02
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10 PORT SHAFT SPEED (RPS)         -0.5054E-01  0.1940E-02 -0.5995E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)       -0.4889E+01  0.1247E-01 -0.4916E+01 -0.4855E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.1811E-02  0.1549E-02 -0.9434E-02  0.1906E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.1265E+00  0.8674E+00 -0.2245E+01  0.2324E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.4730E+00  0.9556E+00 -0.2750E+01  0.2228E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.1373E+01  0.1052E+01 -0.3899E+01  0.1641E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)   -0.9365E+01  0.4443E+00 -0.1066E+02 -0.8073E+01


GROUP NO.  12     TOTAL NO. OF SAMPLES =     4185     27-APR-1988 18:02:37

T1 =   35.0000 SEC.      T2 =   45.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ASTERN, CENT. ONLY - VAR, S.D. AFT/MID


CH DESCRIPTION                       AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1767E+00  0.2956E-03 -0.1800E+00 -0.1755E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)   -0.1291E+02  0.7321E+00 -0.1518E+02 -0.1053E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.1339E+02  0.7318E+00 -0.1570E+02 -0.1100E+02
 4 CENTRE THRUST (N)              -0.8333E+02  0.7450E+01 -0.9727E+02 -0.6596E+02
 5 CENTRE TORQUE (Nm)             -0.4153E+01  0.4119E+00 -0.5403E+01 -0.3078E+01
 6 SUCT. UPPER BENDING (Nm)        0.2059E+01  0.8200E+00 -0.5247E+00  0.3989E+01
 7 SUCT. LOWER BENDING (Nm)        0.8637E+00  0.5217E+00 -0.3627E+00  0.2262E+01
 8 SUCT. TORSION (Nm)             -0.7285E+00  0.2368E+00 -0.1418E+01  0.3283E+00
 9 TOW FORCE (N)                   0.3808E+02  0.1675E+01  0.3329E+02  0.4154E+02
10 PORT SHAFT SPEED (RPS)         -0.5020E-01  0.2286E-02 -0.8304E-01 -0.3190E-01
11 CENTRE SHAFT SPEED (RPS)       -0.5751E+01  0.1595E-01 -0.5791E+01 -0.5674E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.1752E-02  0.1681E-02 -0.1211E-01  0.2440E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.3979E+00  0.1542E+01 -0.5327E+01  0.4342E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.8834E+00  0.1715E+01 -0.6326E+01  0.4262E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.2129E+01  0.1921E+01 -0.8223E+01  0.3571E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)   -0.1313E+02  0.6990E+00 -0.1530E+02 -0.1091E+02


GROUP NO.  12     TOTAL NO. OF SAMPLES =     4185     27-APR-1988 18:02:37

T1 =   59.0000 SEC.      T2 =   65.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD ASTERN, CENT. ONLY - VAR, S.D. AFT/MID


CH DESCRIPTION                       AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1760E+00  0.2309E-03 -0.1795E+00 -0.1749E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)   -0.2070E+02  0.8504E+00 -0.2397E+02 -0.1856E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.2148E+02  0.8427E+00 -0.2476E+02 -0.1933E+02
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  4 CENTRE THRUST (N)               -0.1350E+03  0.9591E+01 -0.1581E+03 -0.1134E+0
  5 CENTRE TORQUE (Nm)              -0.6675E+01  0.7483E+00 -0.8223E+01 -0.4946E+0
  6 SUCT. UPPER BENDING (Nm)         0.9536E+00  0.2335E+01 -0.3810E+01  0.5848E+01
  7 SUCT. LOWER BENDING (Nm)        -0.6448E+00  0.6251E+00 -0.2054E+01  0.9056E+00
  8 SUCT. TORSION (Nm)              -0.2920E+01  0.3765E+00 -0.3961E+01 -0.7504E+00
  9 TOW FORCE (N)                    0.6117E+02  0.4084E+01  0.5393E+02  0.7132E+02
 10 PORT SHAFT SPEED (RPS)          -0.5043E-01  0.1561E-02 -0.6407E-01 -0.4015E-01
 11 CENTRE SHAFT SPEED (RPS)        -0.7286E+01  0.3329E-01 -0.7378E+01 -0.7189E+01
 12 STRBRD. SHAFT SPEED (RPS)       -0.1704E-02  0.1455E-02 -0.1122E-01  0.1550E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)       -0.8915E+00  0.1784E+01 -0.5398E+01  0.4378E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1756E+01  0.1997E+01 -0.6781E+01  0.4156E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)       -0.3784E+01  0.2231E+01 -0.9403E+01  0.2928E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.2100E+02  0.8210E+00 -0.2423E+02 -0.1900E+02


GROUP NO.  13     TOTAL NO. OF SAMPLES =    1781     28-APR-1988 11:03:00

T1 =    6.0000 SEC.     T2 =   16.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
ZERO LEVEL STATS CHECK


CH DESCRIPTION                         AVERAGE       RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)            -0.1050E+00  0.5255E-03 -0.1068E+00 -0.1031E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.1711E-01  0.1008E+00 -0.1118E+01  0.1013E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.1215E-01  0.8401E-01 -0.9500E+00  0.9235E+00
  4 CENTRE THRUST (N)               -0.6546E+00  0.5298E+01 -0.9068E+01  0.9114E+01
  5 CENTRE TORQUE (Nm)               0.5015E-01  0.1500E+00 -0.2744E+00  0.4626E+00
  6 SUCT. UPPER BENDING (Nm)         0.5451E-01  0.9745E-01 -0.2696E+00  0.7054E+00
  7 SUCT. LOWER BENDING (Nm)         0.2207E+00  0.1164E+00 -0.7304E+00  0.9254E+00
  8 SUCT. TORSION (Nm)              -0.1407E-01  0.1243E+00 -0.1205E+01  0.1055E+01
  9 TOW FORCE (N)                   -0.5595E+00  0.6219E+01 -0.1273E+02  0.1248E+02
 10 PORT SHAFT SPEED (RPS)          -0.6300E-02  0.1532E-02 -0.1953E-01  0.1099E-01
 11 CENTRE SHAFT SPEED (RPS)         0.2110E+00  0.3133E-02  0.1857E+00  0.2501E+00
 12 STRBRD. SHAFT SPEED (RPS)       -0.5170E-03  0.1575E-02 -0.1389E-01  0.8375E-02
 13 NOZZLE BN [#1 GAUGE] (Nm)        0.1095E+01  0.1783E+00 -0.3360E+00  0.2639E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)        0.1881E+00  0.1662E+00 -0.1078E+01  0.1446E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)        0.9213E-01  0.1676E+00 -0.1849E+01  0.2047E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)     0.1167E-01  0.1135E+00 -0.1440E+01  0.1119E+01


GROUP NO.  14     TOTAL NO. OF SAMPLES =    2393     28-APR-1988 11:13:32

T1 =    1.0000 SEC.     T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID
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CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)             -0.1390E+00  0.6633E-03 -0.1405E+00 -0.1370E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.5932E+01  0.4482E+00 -0.7511E+01 -0.4600E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.6120E+01  0.4424E+00 -0.7494E+01 -0.4806E+01
 4 CENTRE THRUST (N)                -0.4341E+02  0.6125E+01 -0.5534E+02 -0.2665E+02
 5 CENTRE TORQUE (Nm)               -0.3810E+01  0.3540E+00 -0.4790E+01 -0.2745E+01
 6 SUCT. UPPER BENDING (Nm)         -0.5996E+01  0.3871E+00 -0.7274E+01 -0.4927E+01
 7 SUCT. LOWER BENDING (Nm)         -0.4975E+01  0.2780E+00 -0.5768E+01 -0.4165E+01
 8 SUCT. TORSION (Nm)               -0.6361E+01  0.1550E+00 -0.6753E+01 -0.5520E+01
 9 TOW FORCE (N)                     0.9276E+01  0.2552E+01  0.7448E+00  0.1487E+02
10 PORT SHAFT SPEED (RPS)           -0.3614E-01  0.1549E-02 -0.6324E-01 -0.2695E-01
11 CENTRE SHAFT SPEED (RPS)         -0.3829E+01  0.1151E-01 -0.3854E+01 -0.3790E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.5946E-03  0.1195E-02 -0.9434E-02  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4847E+00  0.6609E+00 -0.2284E+01  0.1258E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.1486E+01  0.7334E+00 -0.3322E+01  0.7451E+00
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2085E+01  0.8433E+00 -0.4208E+01  0.1332E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.5990E+01  0.4428E+00 -0.7337E+01 -0.4194E+01



GROUP NO.  14     TOTAL NO. OF SAMPLES =     2393     28-APR-1988 11:13:32

T1 =   15.0000 SEC.     T2 =   27.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)             -0.1404E+00  0.3675E-03 -0.1434E+00 -0.1369E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1345E+02  0.9716E+00 -0.1585E+02 -0.1050E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1378E+02  0.9877E+00 -0.1629E+02 -0.1078E+02
 4 CENTRE THRUST (N)                -0.8534E+02  0.7316E+01 -0.1024E+03 -0.6469E+02
 5 CENTRE TORQUE (Nm)               -0.5635E+01  0.3940E+00 -0.6603E+01 -0.4430E+01
 6 SUCT. UPPER BENDING (Nm)         -0.3984E+01  0.6703E+00 -0.5595E+01 -0.1624E+01
 7 SUCT. LOWER BENDING (Nm)         -0.3818E+01  0.4987E+00 -0.5839E+01 -0.2386E+01
 8 SUCT. TORSION (Nm)               -0.7280E+01  0.2778E+00 -0.8320E+01 -0.5957E+01
 9 TOW FORCE (N)                     0.1787E+02  0.2904E+01  0.8351E+01  0.2639E+02
10 PORT SHAFT SPEED (RPS)           -0.3664E-01  0.1753E-02 -0.5747E-01 -0.2695E-01
11 CENTRE SHAFT SPEED (RPS)         -0.5345E+01  0.2102E-01 -0.5392E+01 -0.5294E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.5754E-03  0.1306E-02 -0.1656E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.3549E+01  0.1327E+01 -0.7632E+01 -0.1723E-01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.5114E+01  0.1483E+01 -0.9772E+01 -0.5170E+00
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.6682E+01  0.1687E+01 -0.1207E+02 -0.2314E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1356E+02  0.9652E+00 -0.1604E+02 -0.1051E+02



GROUP NO.  14     TOTAL NO. OF SAMPLES =     2393     28-APR-1988 11:13:32

T1 =   36.0000 SEC.     T2 =   43.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1423E+00  0.2222E-03 -0.1432E+00 -0.1413E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.2624E+02  0.1521E+01 -0.3095E+02 -0.2193E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2687E+02  0.1564E+01 -0.3169E+02 -0.2248E+02
 4 CENTRE THRUST (N)                -0.1523E+03  0.7501E+01 -0.1713E+03 -0.1283E+03
 5 CENTRE TORQUE (Nm)               -0.9008E+01  0.6821E+00 -0.1150E+02 -0.7157E+01
 6 SUCT. UPPER BENDING (Nm)         -0.5411E+00  0.1134E+01 -0.3068E+01  0.2493E+01
 7 SUCT. LOWER BENDING (Nm)         -0.1843E+01  0.6227E+00 -0.3091E+01 -0.4133E+00
 8 SUCT. TORSION (Nm)               -0.8963E+01  0.3970E+00 -0.1009E+02 -0.7832E+01
 9 TOW FORCE (N)                     0.2744E+02  0.1172E+01  0.2378E+02  0.3030E+02
10 PORT SHAFT SPEED (RPS)           -0.3735E-01  0.1805E-02 -0.5417E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)         -0.7095E+01  0.5544E-01 -0.7261E+01 -0.6955E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.6031E-03  0.2115E-02 -0.1923E-01  0.1817E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.9348E+01  0.2232E+01 -0.1564E+02 -0.2532E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.1205E+02  0.2547E+01 -0.1959E+02 -0.4478E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.1532E+02  0.2891E+01 -0.2422E+02 -0.6674E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.2637E+02  0.1506E+01 -0.3101E+02 -0.2211E+02



GROUP NO.  15     TOTAL NO. OF SAMPLES =    2384     28-APR-1988 11:27:03

T1 =     1.0000 SEC.     T2 =    10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1620E+00  0.2738E-03 -0.1630E+00 -0.1586E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.7852E-01  0.6288E-01 -0.4077E+00  0.7358E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.7823E-01  0.1063E+00 -0.1321E+01  0.7702E+00
 4 CENTRE THRUST (N)                 0.7026E+01  0.5445E+01 -0.2782E+01  0.1727E+02
 5 CENTRE TORQUE (Nm)               -0.1211E+00  0.1438E+00 -0.4820E+00  0.3554E+00
 6 SUCT. UPPER BENDING (Nm)         -0.5137E-01  0.7015E-01 -0.3689E+00  0.6422E+00
 7 SUCT. LOWER BENDING (Nm)          0.3360E-01  0.9927E-01 -0.4953E+00  0.7554E+00
 8 SUCT. TORSION (Nm)               -0.4761E-01  0.1298E+00 -0.1666E+01  0.1210E+01
 9 TOW FORCE (N)                    -0.2692E+01  0.2813E+01 -0.1056E+02  0.6178E+01
10 PORT SHAFT SPEED (RPS)           -0.4484E-01  0.1718E-02 -0.6407E-01 -0.2860E-01
11 CENTRE SHAFT SPEED (RPS)         -0.5793E+00  0.4781E-02 -0.6277E+00 -0.5582E+00
12 STRBRD. SHAFT SPEED (RPS)        -0.5591E-03  0.1802E-02 -0.7653E-02  0.2084E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         0.6351E+00  0.1715E+00 -0.1390E+01  0.1904E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1179E+00  0.1922E+00 -0.2073E+01  0.7963E+00
15 NOZZLE BN [#3 GAUGE] (Nm)         0.8623E-01  0.2018E+00 -0.1985E+01  0.1803E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.8274E-01  0.1380E+00 -0.1736E+01  0.1073E+01
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GROUP NO.  15     TOTAL NO. OF SAMPLES =    2384     28-APR-1988 11:27:03

T1 =   14.0000 SEC.     T2 =   23.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1620E+00  0.3115E-03 -0.1641E+00 -0.1568E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1997E+01  0.1360E+00 -0.2773E+01 -0.1525E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.2047E+01  0.1357E+00 -0.2407E+01 -0.1348E+01
 4 CENTRE THRUST (N)                 -0.6900E+01  0.5971E+01 -0.1714E+02  0.4260E+01
 5 CENTRE TORQUE (Nm)                -0.8772E+00  0.2081E+00 -0.1486E+01 -0.2883E+00
 6 SUCT. UPPER BENDING (Nm)           0.4086E+00  0.1575E+00 -0.6194E-01  0.8047E+00
 7 SUCT. LOWER BENDING (Nm)           0.4096E+00  0.1338E+00 -0.5305E+00  0.7906E+00
 8 SUCT. TORSION (Nm)                -0.8776E-01  0.1415E+00 -0.1512E+01  0.1390E+01
 9 TOW FORCE (N)                      0.3626E+01  0.2302E+01 -0.3384E+01  0.9437E+01
10 PORT SHAFT SPEED (RPS)            -0.4521E-01  0.1595E-02 -0.6902E-01 -0.3768E-01
11 CENTRE SHAFT SPEED (RPS)          -0.2460E+01  0.7825E-02 -0.2475E+01 -0.2414E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.7368E-03  0.1862E-02 -0.2457E-01  0.1728E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          0.7417E+00  0.2954E+00 -0.1922E+01  0.2293E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          0.1511E+00  0.3230E+00 -0.3410E+01  0.7613E+00
15 NOZZLE BN [#3 GAUGE] (Nm)          0.2434E-01  0.2939E+00 -0.6629E+00  0.1196E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.2036E+01  0.1750E+00 -0.3544E+01 -0.1228E+00
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GROUP NO.  15     TOTAL NO. OF SAMPLES =    2384     28-APR-1988 11:27:03

T1 =   27.5000 SEC.     T2 =   34.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1609E+00  0.1001E-03 -0.1615E+00 -0.1606E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1102E+02  0.7432E+00 -0.1348E+02 -0.9010E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.1146E+02  0.7084E+00 -0.1316E+02 -0.9466E+01
 4 CENTRE THRUST (N)                 -0.6517E+02  0.6882E+01 -0.7961E+02 -0.4921E+02
 5 CENTRE TORQUE (Nm)                -0.4457E+01  0.3670E+00 -0.5216E+01 -0.3306E+01
 6 SUCT. UPPER BENDING (Nm)           0.2235E+01  0.2117E+01 -0.1903E+01  0.6546E+01
 7 SUCT. LOWER BENDING (Nm)           0.1196E+01  0.5427E+00 -0.2839E+00  0.2852E+01
 8 SUCT. TORSION (Nm)                -0.6644E+00  0.2397E+00 -0.1512E+01  0.2887E-01
 9 TOW FORCE (N)                      0.3499E+02  0.9762E+01  0.1226E+02  0.6094E+02
10 PORT SHAFT SPEED (RPS)            -0.4489E-01  0.1111E-02 -0.5500E-01 -0.4262E-01
11 CENTRE SHAFT SPEED (RPS)          -0.5435E+01  0.1870E-01 -0.5501E+01 -0.5362E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.7289E-03  0.2080E-02 -0.1389E-01  0.2707E-01
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13 NOZZLE BN [#1 GAUGE] (Nm)         0.1223E+01  0.5014E+01 -0.7659E+01  0.1086E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.4727E+00  0.5588E+01 -0.9440E+01  0.1114E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.3917E+00  0.6217E+01 -0.1139E+02  0.1153E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1133E+02  0.6624E+00 -0.1289E+02 -0.9246E+01



GROUP NO.  15     TOTAL NO. OF SAMPLES =     2384     28-APR-1988 11:27:03

T1 =    39.0000 SEC.      T2 =    45.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN BOLLARD-CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1608E+00  0.2086E-03 -0.1619E+00 -0.1585E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1959E+02  0.8219E+00 -0.2172E+02 -0.1621E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2037E+02  0.8321E+00 -0.2242E+02 -0.1696E+02
 4 CENTRE THRUST (N)                -0.1217E+03  0.8879E+01 -0.1463E+03 -0.9966E+02
 5 CENTRE TORQUE (Nm)               -0.7514E+01  0.4897E+00 -0.8520E+01 -0.6219E+01
 6 SUCT. UPPER BENDING (Nm)          0.4135E+01  0.1964E+01 -0.1290E+01  0.8225E+01
 7 SUCT. LOWER BENDING (Nm)          0.2224E+01  0.7427E+00  0.3326E+00  0.3961E+01
 8 SUCT. TORSION (Nm)               -0.1307E+01  0.3470E+00 -0.2385E+01 -0.2280E+00
 9 TOW FORCE (N)                     0.6332E+02  0.7491E+01  0.4877E+02  0.7681E+02
10 PORT SHAFT SPEED (RPS)           -0.4515E-01  0.2432E-02 -0.7562E-01 -0.2448E-01
11 CENTRE SHAFT SPEED (RPS)         -0.7192E+01  0.1994E-01 -0.7245E+01 -0.7146E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.8934E-03  0.1909E-02 -0.2902E-01  0.4813E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.1029E+01  0.2050E+01 -0.4153E+01  0.7393E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1640E+00  0.2259E+01 -0.5479E+01  0.7071E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.1430E+01  0.2452E+01 -0.7954E+01  0.6057E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.2008E+02  0.8164E+00 -0.2210E+02 -0.1612E+02



GROUP NO.  16     TOTAL NO. OF SAMPLES =     2521     28-APR-1988 11:42:32

T1 =     1.0000 SEC.      T2 =    11.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K ASTERN, Vm=0.266 m/s, CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1849E+00  0.4692E-03 -0.1878E+00 -0.1810E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.9136E+00  0.4679E+00 -0.2487E+01 -0.9581E-01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.9016E+00  0.4568E+00 -0.1809E+01 -0.7155E-01
 4 CENTRE THRUST (N)                 0.2542E+01  0.5469E+01 -0.6960E+01  0.1262E+02
 5 CENTRE TORQUE (Nm)               -0.7413E+00  0.1679E+00 -0.1115E+01 -0.2986E+00
 6 SUCT. UPPER BENDING (Nm)         -0.1755E+01  0.2493E+01 -0.6074E+01  0.2556E+01
 7 SUCT. LOWER BENDING (Nm)        -0.1632E+01  0.2067E+01 -0.5639E+01  0.1936E+01
 8 SUCT. TORSION (Nm)               0.1800E+00  0.7932E+00 -0.1332E+01  0.2649E+01
 9 TOW FORCE (N)                   -0.1017E+02  0.1978E+02 -0.6010E+02  0.2965E+02
10 PORT SHAFT SPEED (RPS)          -0.4950E-01  0.2054E-02 -0.8056E-01 -0.2943E-01
11 CENTRE SHAFT SPEED (RPS)        -0.5613E+00  0.4699E-02 -0.6141E+00 -0.5260E+00
12 STRBRD. SHAFT SPEED (RPS)       -0.9027E-03  0.1996E-02 -0.2368E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.9546E+00  0.6268E+00 -0.4188E+01  0.2035E+00
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.4244E+00  0.6857E+00 -0.1868E+01  0.1709E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.6183E+00  0.7888E+00 -0.3201E+01  0.2304E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.8503E+00  0.4791E+00 -0.3238E+01  0.6282E+00


GROUP NO.  16     TOTAL NO. OF SAMPLES =    2521     28-APR-1988 11:42:32

T1 =   15.0000 SEC.     T2 =   22.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K ASTERN, Vm=0.266 m/s, CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                        AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1847E+00  0.1329E-03 -0.1858E+00 -0.1840E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.5251E+01  0.6017E+00 -0.6671E+01 -0.3760E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.5388E+01  0.6199E+00 -0.8244E+01 -0.3900E+01
 4 CENTRE THRUST (N)               -0.2800E+02  0.6244E+01 -0.4149E+02 -0.1297E+02
 5 CENTRE TORQUE (Nm)              -0.2742E+01  0.2602E+00 -0.3344E+01 -0.2053E+01
 6 SUCT. UPPER BENDING (Nm)        -0.7918E+00  0.2208E+01 -0.4666E+01  0.2953E+01
 7 SUCT. LOWER BENDING (Nm)        -0.9178E+00  0.1816E+01 -0.3913E+01  0.2200E+01
 8 SUCT. TORSION (Nm)              -0.3867E-01  0.7113E+00 -0.1230E+01  0.1185E+01
 9 TOW FORCE (N)                   -0.1047E+01  0.1666E+02 -0.2903E+02  0.2530E+02
10 PORT SHAFT SPEED (RPS)          -0.4970E-01  0.1737E-02 -0.7067E-01 -0.4180E-01
11 CENTRE SHAFT SPEED (RPS)        -0.3776E+01  0.9579E-02 -0.3798E+01 -0.3752E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.9912E-03  0.1228E-02 -0.1032E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.1591E+01  0.1213E+01 -0.4543E+01  0.1195E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1457E+01  0.1362E+01 -0.4708E+01  0.1743E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.2112E+01  0.1506E+01 -0.5774E+01  0.1410E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.5250E+01  0.5810E+00 -0.7243E+01 -0.3794E+01


GROUP NO.  16     TOTAL NO. OF SAMPLES =    2521     28-APR-1988 11:42:32

T1 =   28.0000 SEC.     T2 =   36.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K ASTERN, Vm=0.266 m/s, CENT. ONLY-VAR, S.D. AFT/MID


CH DESCRIPTION                        AVERAGE       RMS        MINIMUM      MAXIMUM
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  1 CARRIAGE SPEED (M/S)            -0.1852E+00  0.1400E-03 -0.1865E+00 -0.1847E+0
  2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.9719E+01  0.9537E+00 -0.1197E+02 -0.6749E+0
  3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.1005E+02  0.9334E+00 -0.1259E+02 -0.7131E+01
  4 CENTRE THRUST (N)               -0.5903E+02  0.6872E+01 -0.7332E+02 -0.4297E+02
  5 CENTRE TORQUE (Nm)              -0.4452E+01  0.3537E+00 -0.5212E+01 -0.3448E+01
  6 SUCT. UPPER BENDING (Nm)         0.2913E+00  0.3367E+01 -0.7392E+01  0.7376E+01
  7 SUCT. LOWER BENDING (Nm)        -0.4332E+00  0.1941E+01 -0.4424E+01  0.3327E+01
  8 SUCT. TORSION (Nm)              -0.3420E+00  0.7829E+00 -0.3156E+01  0.1185E+01
  9 TOW FORCE (N)                    0.1269E+02  0.1517E+02 -0.1425E+02  0.4334E+02
 10 PORT SHAFT SPEED (RPS)          -0.5005E-01  0.1312E-02 -0.6654E-01 -0.3685E-01
 11 CENTRE SHAFT SPEED (RPS)        -0.5256E+01  0.1704E-01 -0.5303E+01 -0.5204E+01
 12 STRBRD. SHAFT SPEED (RPS)       -0.8914E-03  0.1017E-02 -0.4982E-02  0.1016E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)       -0.1250E+01  0.5983E+01 -0.1180E+02  0.1051E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1518E+01  0.6669E+01 -0.1333E+02  0.1152E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)       -0.2489E+01  0.7389E+01 -0.1553E+02  0.1195E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.9823E+01  0.8838E+00 -0.1180E+02 -0.6826E+01


 GROUP NO.  16     TOTAL NO. OF SAMPLES =    2521     28-APR-1988 11:42:32

 T1 =    41.0000 SEC.     T2 =    49.0000 SEC.

 PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
 Vs=2K ASTERN, Vm=0.266 m/s, CENT. ONLY-VAR, S.D. AFT/MID


 CH DESCRIPTION                       AVERAGE       RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)            -0.1866E+00  0.4636E-03 -0.1877E+00 -0.1857E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.1822E+02  0.9210E+00 -0.2115E+02 -0.1434E+02
  3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.1885E+02  0.9414E+00 -0.2198E+02 -0.1490E+02
  4 CENTRE THRUST (N)               -0.1147E+03  0.9788E+01 -0.1385E+03 -0.8876E+02
  5 CENTRE TORQUE (Nm)              -0.7451E+01  0.5067E+00 -0.8853E+01 -0.6223E+01
  6 SUCT. UPPER BENDING (Nm)         0.2387E+01  0.2103E+01 -0.3294E+01  0.6654E+01
  7 SUCT. LOWER BENDING (Nm)         0.7256E+00  0.1042E+01 -0.1728E+01  0.3539E+01
  8 SUCT. TORSION (Nm)              -0.1017E+01  0.4455E+00 -0.2719E+01  0.5456E-01
  9 TOW FORCE (N)                    0.3710E+02  0.8640E+01  0.1987E+02  0.5377E+02
 10 PORT SHAFT SPEED (RPS)          -0.5095E-01  0.2345E-02 -0.8386E-01 -0.2613E-01
 11 CENTRE SHAFT SPEED (RPS)        -0.7088E+01  0.2068E-01 -0.7143E+01 -0.7034E+01
 12 STRBRD. SHAFT SPEED (RPS)       -0.9203E-03  0.1688E-02 -0.2101E-01  0.1639E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)       -0.1895E+01  0.2085E+01 -0.6845E+01  0.5481E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)       -0.2578E+01  0.2300E+01 -0.8073E+01  0.5494E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)       -0.4299E+01  0.2568E+01 -0.1074E+02  0.4841E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.1844E+02  0.9002E+00 -0.2137E+02 -0.1467E+02


 GROUP NO.  17     TOTAL NO. OF SAMPLES =    2154     28-APR-1988 11:59:38

 T1 =     4.5000 SEC.     T2 =     7.5000 SEC.

 PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
 vs=0, AHEAD BOLLARD-CENT. ONLY-VAR, S.D. 5cm FWD/MID
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CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1566E+00  0.2455E-02 -0.1602E+00 -0.1513E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.2841E-01  0.1419E+00 -0.1195E+01  0.1066E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.5106E-01  0.1091E+00 -0.1804E+00  0.1177E+01
 4 CENTRE THRUST (N)                 0.1856E+02  0.1264E+01  0.1548E+02  0.2061E+02
 5 CENTRE TORQUE (Nm)                0.8827E-01  0.1166E+00 -0.1499E+00  0.2862E+00
 6 SUCT. UPPER BENDING (Nm)          0.6807E-01  0.2935E+00 -0.4901E+00  0.6112E+00
 7 SUCT. LOWER BENDING (Nm)         -0.8077E+00  0.2626E+00 -0.1702E+01 -0.1873E+00
 8 SUCT. TORSION (Nm)               -0.9935E-02  0.1664E+00 -0.8573E+00  0.3498E+00
 9 TOW FORCE (N)                     0.2102E+01  0.3791E+01 -0.1034E+02  0.8351E+01
10 PORT SHAFT SPEED (RPS)            -0.3271E-01  0.1698E-02 -0.4345E-01 -0.2778E-01
11 CENTRE SHAFT SPEED (RPS)         -0.4031E-02  0.5395E-02 -0.1256E-01  0.3997E-01
12 STRBRD. SHAFT SPEED (RPS)        -0.1390E-02  0.2089E-02 -0.1032E-01  0.1906E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4226E+00  0.2454E+00 -0.3207E+01 -0.5477E-01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.1219E+00  0.1357E+00 -0.2907E+00  0.1182E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.1069E+00  0.1492E+00 -0.1312E+01  0.5104E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.3014E-03  0.1128E+00 -0.6707E+00  0.1026E+01



GROUP NO.  17     TOTAL NO. OF SAMPLES =     2154     28-APR-1988 11:59:38

T1 =    10.0000 SEC.      T2 =    17.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
vs=0, AHEAD BOLLARD-CENT. ONLY-VAR, S.D. 5cm FWD/MID


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1658E+00  0.1683E-02 -0.1690E+00 -0.1623E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.5620E+00  0.1380E+00 -0.1455E+01  0.9880E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.4807E+00  0.1393E+00 -0.1266E+01  0.1096E+01
 4 CENTRE THRUST (N)                 0.2591E+02  0.5799E+01  0.1536E+02  0.3541E+02
 5 CENTRE TORQUE (Nm)                0.1395E+01  0.1938E+00  0.8883E+00  0.1937E+01
 6 SUCT. UPPER BENDING (Nm)          0.5202E+01  0.6278E+00  0.4060E+01  0.6587E+01
 7 SUCT. LOWER BENDING (Nm)          0.3830E+01  0.5298E+00  0.2015E+01  0.4956E+01
 8 SUCT. TORSION (Nm)                0.3511E+01  0.2637E+00  0.2738E+01  0.4459E+01
 9 TOW FORCE (N)                    -0.1545E+02  0.4773E+01 -0.2512E+02 -0.2950E+01
10 PORT SHAFT SPEED (RPS)           -0.3729E-01  0.1256E-02 -0.4510E-01 -0.3355E-01
11 CENTRE SHAFT SPEED (RPS)          0.2737E+01  0.6961E-02  0.2677E+01  0.2753E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1258E-02  0.1723E-02 -0.4982E-02  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.3460E+01  0.2443E+00 -0.5828E+01 -0.1897E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.3603E+01  0.2147E+00 -0.4497E+01 -0.2289E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.3993E+01  0.2036E+00 -0.5137E+01 -0.3100E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.3986E+00  0.1203E+00 -0.6151E+00  0.6922E+00
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GROUP NO.  17     TOTAL NO. OF SAMPLES =    2154      28-APR-1988 11:59:38

T1 =    25.0000 SEC.      T2 =    29.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
vs=0, AHEAD BOLLARD-CENT. ONLY-VAR, S.D. 5cm FWD/MID


CH DESCRIPTION                             AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1731E+00  0.6491E-03 -0.1742E+00 -0.1718E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -0.5015E+00  0.9263E+00 -0.3560E+01  0.1430E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.7031E+00  0.8943E+00 -0.3656E+01  0.1204E+01
 4 CENTRE THRUST (N)                     0.1539E+03  0.1081E+02  0.1300E+03  0.1919E+03
 5 CENTRE TORQUE (Nm)                    0.8838E+01  0.7389E+00  0.6518E+01  0.1096E+02
 6 SUCT. UPPER BENDING (Nm)              0.6299E+02  0.2390E+01  0.5748E+02  0.6876E+02
 7 SUCT. LOWER BENDING (Nm)              0.4890E+02  0.1883E+01  0.4478E+02  0.5328E+02
 8 SUCT. TORSION (Nm)                    0.5137E+02  0.1718E+01  0.4792E+02  0.5508E+02
 9 TOW FORCE (N)                        -0.9097E+02  0.1728E+02 -0.1157E+03 -0.6380E+02
10 PORT SHAFT SPEED (RPS)               -0.4114E-01  0.2039E-02 -0.5417E-01 -0.2036E-01
11 CENTRE SHAFT SPEED (RPS)              0.7856E+01  0.3966E-01  0.7755E+01  0.7953E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.1531E-02  0.1062E-02 -0.1032E-01  0.3032E-02
13 NOZZLE BN [#1 GAUGE] (Nm)             0.4738E+01  0.5462E+01 -0.9228E+01  0.1794E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.3683E+01  0.5972E+01 -0.1182E+02  0.1759E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.2434E+01  0.6621E+01 -0.1464E+02  0.1742E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)         -0.6308E+00  0.8664E+00 -0.3424E+01  0.1248E+01
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GROUP NO.  17     TOTAL NO. OF SAMPLES =    2154      28-APR-1988 11:59:38

T1 =    36.0000 SEC.      T2 =    40.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
vs=0, AHEAD BOLLARD-CENT. ONLY-VAR, S.D. 5cm FWD/MID


CH DESCRIPTION                             AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1769E+00  0.3718E-03 -0.1776E+00 -0.1753E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -0.3688E+01  0.5872E+00 -0.5977E+01 -0.2390E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.3509E+01  0.6176E+00 -0.5719E+01 -0.2108E+01
 4 CENTRE THRUST (N)                     0.9098E+02  0.9805E+01  0.7058E+02  0.1147E+03
 5 CENTRE TORQUE (Nm)                    0.5303E+01  0.3511E+00  0.4376E+01  0.6169E+01
 6 SUCT. UPPER BENDING (Nm)              0.6017E+02  0.3156E+01  0.5152E+02  0.6851E+02
 7 SUCT. LOWER BENDING (Nm)              0.4822E+02  0.2657E+01  0.4221E+02  0.5454E+02
 8 SUCT. TORSION (Nm)                    0.4552E+02  0.1971E+01  0.4103E+02  0.4969E+02
 9 TOW FORCE (N)                        -0.6109E+02  0.3433E+01 -0.6967E+02 -0.5424E+02
10 PORT SHAFT SPEED (RPS)               -0.4334E-01  0.1462E-02 -0.5087E-01 -0.2778E-01
11 CENTRE SHAFT SPEED (RPS)              0.6059E+01  0.1885E-01  0.5991E+01  0.6108E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.1478E-02  0.1088E-02 -0.1211E-01  0.3032E-02
13 NOZZLE BN [#1 GAUGE] (Nm)            -0.8441E+01  0.4278E+01 -0.1730E+02  0.1468E+01
14 NOZZLE BN [#2 GAUGE] (Nm)            -0.9867E+01  0.4781E+01 -0.1989E+02  0.1077E+01
15 NOZZLE BN [#3 GAUGE] (Nm)            -0.1159E+02  0.5203E+01 -0.2261E+02  0.1173E+00
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16 NOZZLE TORSION [ #1 Gg] (Nm)  -0.3351E+01  0.6310E+00 -0.5483E+01 -0.1895E+01


GROUP NO.  18     TOTAL NO. OF SAMPLES =    2491     28-APR-1988 12:04:46

T1 =    1.5000 SEC.     T2 =    6.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K AHEAD, Vm=0.266 m/s, CENT. ONLY-VAR, S.D 5cm FWD/MID


CH DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1176E+00  0.1213E-02 -0.1214E+00 -0.1147E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.7621E-01  0.1018E+00 -0.3633E+00  0.8841E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.8959E-01  0.4645E-01 -0.2890E+00  0.3355E+00
 4 CENTRE THRUST (N)                 0.1071E+02  0.5435E+01  0.2112E+01  0.1902E+02
 5 CENTRE TORQUE (Nm)                0.5957E+00  0.2390E+00  0.5777E-01  0.1075E+01
 6 SUCT. UPPER BENDING (Nm)          0.3693E+01  0.7887E+00  0.1803E+01  0.5161E+01
 7 SUCT. LOWER BENDING (Nm)          0.2382E+01  0.6291E+00  0.1046E+01  0.3494E+01
 8 SUCT. TORSION (Nm)                0.1405E+01  0.4050E+00  0.5296E+00  0.2148E+01
 9 TOW FORCE (N)                     0.8056E+01  0.4931E+01 -0.4905E+01  0.1835E+02
10 PORT SHAFT SPEED (RPS)           -0.1286E-01  0.1800E-02 -0.2448E-01 -0.7159E-02
11 CENTRE SHAFT SPEED (RPS)          0.2270E+00  0.3401E-02  0.1976E+00  0.2602E+00
12 STRBRD. SHAFT SPEED (RPS)        -0.1296E-02  0.1388E-02 -0.7653E-02  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.2153E+00  0.3356E+00 -0.1684E+01  0.1397E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.3115E+00  0.4012E+00 -0.1027E+01  0.1497E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2019E+00  0.3144E+00 -0.5618E+00  0.1082E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1235E+00  0.1542E+00 -0.1227E+01  0.1332E+01


GROUP NO.  18     TOTAL NO. OF SAMPLES =    2491     28-APR-1988 12:04:46

T1 =   12.0000 SEC.     T2 =   18.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K AHEAD, Vm=0.266 m/s, CENT. ONLY-VAR, S.D 5cm FWD/MID


CH DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1197E+00  0.1216E-02 -0.1236E+00 -0.1170E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.6475E+00  0.1111E+00 -0.1195E+01  0.1824E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.5940E+00  0.9736E-01 -0.8320E+00  0.9117E-01
 4 CENTRE THRUST (N)                 0.2092E+02  0.5682E+01  0.1055E+02  0.2976E+02
 5 CENTRE TORQUE (Nm)                0.1151E+01  0.2774E+00  0.4730E+00  0.1805E+01
 6 SUCT. UPPER BENDING (Nm)          0.9108E+01  0.1801E+01  0.5233E+01  0.1294E+02
 7 SUCT. LOWER BENDING (Nm)          0.7195E+01  0.1488E+01  0.4199E+01  0.1019E+02
 8 SUCT. TORSION (Nm)                0.5191E+01  0.9414E+00  0.3149E+01  0.7053E+01
 9 TOW FORCE (N)                    -0.8392E+00  0.2795E+01 -0.7513E+01  0.5743E+01
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10 PORT SHAFT SPEED (RPS)          -0.1379E-01  0.1519E-02 -0.2201E-01 -0.9634E-02
11 CENTRE SHAFT SPEED (RPS)         0.2424E+01  0.7640E-02  0.2399E+01  0.2448E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.1515E-02  0.2085E-02 -0.1567E-01  0.1817E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.2040E+01  0.3609E+00 -0.3845E+01 -0.1365E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1683E+01  0.4176E+00 -0.2920E+01  0.5991E-01
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.2048E+01  0.3491E+00 -0.2814E+01 -0.9550E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.6223E+00  0.9635E-01 -0.1032E+01 -0.3092E+00


GROUP NO.  18     TOTAL NO. OF SAMPLES =    2491     28-APR-1988 12:04:46

T1 =   22.0000 SEC.     T2 =   29.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K AHEAD, Vm=0.266 m/s, CENT. ONLY-VAR, S.D 5cm FWD/MID


CH DESCRIPTION                       AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1210E+00  0.1350E-02 -0.1243E+00 -0.1171E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.1637E+01  0.2441E+00 -0.2676E+01 -0.6752E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.1440E+01  0.2427E+00 -0.2027E+01 -0.6691E+00
 4 CENTRE THRUST (N)                0.3936E+02  0.6304E+01  0.2698E+02  0.5053E+02
 5 CENTRE TORQUE (Nm)               0.2323E+01  0.3143E+00  0.1407E+01  0.2992E+01
 6 SUCT. UPPER BENDING (Nm)         0.2181E+02  0.1100E+01  0.1915E+02  0.2455E+02
 7 SUCT. LOWER BENDING (Nm)         0.1750E+02  0.8933E+00  0.1538E+02  0.1988E+02
 8 SUCT. TORSION (Nm)               0.1384E+02  0.6237E+00  0.1234E+02  0.1535E+02
 9 TOW FORCE (N)                   -0.2032E+02  0.4884E+01 -0.3011E+02 -0.7730E+01
10 PORT SHAFT SPEED (RPS)          -0.1446E-01  0.2459E-02 -0.4345E-01  0.6862E-02
11 CENTRE SHAFT SPEED (RPS)         0.4137E+01  0.1118E-01  0.4112E+01  0.4173E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.1595E-02  0.1701E-02 -0.1032E-01  0.1728E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.6404E+01  0.5514E+00 -0.7811E+01 -0.4730E+01
14 NOZZLE BN [#2 GAUGE] (Nm)       -0.6641E+01  0.6383E+00 -0.8739E+01 -0.4708E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       -0.7540E+01  0.6339E+00 -0.1036E+02 -0.5566E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.1432E+01  0.2454E+00 -0.2590E+01 -0.8098E+00


GROUP NO.  18     TOTAL NO. OF SAMPLES =    2491     28-APR-1988 12:04:46

T1 =   34.0000 SEC.     T2 =   40.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K AHEAD, Vm=0.266 m/s, CENT. ONLY-VAR, S.D 5cm FWD/MID


CH DESCRIPTION                       AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1246E+00  0.1136E-02 -0.1277E+00 -0.1223E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.3316E+01  0.6014E+00 -0.4885E+01 -0.1559E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.3235E+01  0.5852E+00 -0.4742E+01 -0.1701E+01
 4 CENTRE THRUST (N)                 0.9533E+02  0.1052E+02  0.7106E+02  0.1172E+03
 5 CENTRE TORQUE (Nm)                0.5535E+01  0.4199E+00  0.4463E+01  0.6788E+01
 6 SUCT. UPPER BENDING (Nm)          0.6212E+02  0.2205E+01  0.5611E+02  0.6810E+02
 7 SUCT. LOWER BENDING (Nm)          0.4971E+02  0.1930E+01  0.4450E+02  0.5509E+02
 8 SUCT. TORSION (Nm)                0.4636E+02  0.1750E+01  0.4268E+02  0.5038E+02
 9 TOW FORCE (N)                    -0.4141E+02  0.8109E+01 -0.5945E+02 -0.2338E+02
10 PORT SHAFT SPEED (RPS)           -0.1635E-01  0.1374E-02 -0.2283E-01 -0.9634E-02
11 CENTRE SHAFT SPEED (RPS)          0.6289E+01  0.1841E-01  0.6252E+01  0.6333E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1636E-02  0.1999E-02 -0.2101E-01  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4873E+01  0.3623E+01 -0.1401E+02  0.6108E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.5588E+01  0.3963E+01 -0.1561E+02  0.6510E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.7082E+01  0.4289E+01 -0.1775E+02  0.6086E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.3196E+01  0.5953E+00 -0.4732E+01 -0.9211E+00



GROUP NO.  18     TOTAL NO. OF SAMPLES =     2491     28-APR-1988 12:04:46

T1 =    43.0000 SEC.      T2 =    48.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2K AHEAD, Vm=0.266 m/s, CENT. ONLY-VAR, S.D 5cm FWD/MID


CH DESCRIPTION                       AVERAGE       RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1266E+00  0.9989E-03 -0.1291E+00 -0.1245E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.8853E+00  0.1018E+01 -0.3794E+01  0.1690E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1120E+01  0.9657E+00 -0.4036E+01  0.1204E+01
 4 CENTRE THRUST (N)                 0.1483E+03  0.1266E+02  0.1126E+03  0.1833E+03
 5 CENTRE TORQUE (Nm)                0.8562E+01  0.5573E+00  0.7065E+01  0.1010E+02
 6 SUCT. UPPER BENDING (Nm)          0.6405E+02  0.1750E+01  0.5918E+02  0.6853E+02
 7 SUCT. LOWER BENDING (Nm)          0.4994E+02  0.1455E+01  0.4635E+02  0.5393E+02
 8 SUCT. TORSION (Nm)                0.5060E+02  0.2040E+01  0.4699E+02  0.5424E+02
 9 TOW FORCE (N)                    -0.6314E+02  0.6741E+01 -0.7727E+02 -0.4946E+02
10 PORT SHAFT SPEED (RPS)           -0.1731E-01  0.1497E-02 -0.2118E-01 -0.4685E-02
11 CENTRE SHAFT SPEED (RPS)          0.7826E+01  0.2083E-01  0.7774E+01  0.7885E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1658E-02  0.1601E-02 -0.1389E-01  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         0.5804E+01  0.5725E+01 -0.6501E+01  0.1886E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.5353E+01  0.6265E+01 -0.8389E+01  0.1966E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         0.4225E+01  0.6940E+01 -0.1086E+02  0.2003E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1138E+01  0.9496E+00 -0.4064E+01  0.1026E+01



GROUP NO.  19     TOTAL NO. OF SAMPLES =     1816     28-APR-1988 12:19:30

T1 =     1.0000 SEC.      T2 =     7.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. 10 Cm. FWD. MID.
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CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1744E+00  0.8058E-03 -0.1769E+00 -0.1712E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -0.6710E-01  0.1115E+00 -0.8051E+00  0.8321E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.1043E+00  0.7856E-01 -0.7234E+00  0.5256E+00
 4 CENTRE THRUST (N)                     0.1201E+02  0.4637E+01  0.3703E+01  0.2014E+02
 5 CENTRE TORQUE (Nm)                    0.6527E+00  0.1239E+00  0.3900E+00  0.9782E+00
 6 SUCT. UPPER BENDING (Nm)              0.1542E+00  0.8149E-01 -0.2997E+00  0.6572E+00
 7 SUCT. LOWER BENDING (Nm)             -0.1343E+00  0.1043E+00 -0.9587E+00  0.5562E+00
 8 SUCT. TORSION (Nm)                    0.3537E-01  0.1148E+00 -0.7002E+00  0.1200E+01
 9 TOW FORCE (N)                        -0.1296E+01  0.2482E+01 -0.8382E+01  0.4656E+01
10 PORT SHAFT SPEED (RPS)               -0.5067E-01  0.2683E-02 -0.7644E-01 -0.3768E-01
11 CENTRE SHAFT SPEED (RPS)              0.1764E+00  0.2608E-02  0.1671E+00  0.2009E+00
12 STRBRD. SHAFT SPEED (RPS)            -0.1665E-02  0.2106E-02 -0.2635E-01  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)            -0.2197E+01  0.2011E+00 -0.3242E+01 -0.4444E+00
14 NOZZLE BN [#2 GAUGE] (Nm)             0.8775E-01  0.1752E+00 -0.1237E+01  0.1392E+01
15 NOZZLE BN [#3 GAUGE] (Nm)             0.9590E-01  0.1894E+00 -0.1384E+01  0.1726E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)         -0.3914E-01  0.1006E+00 -0.1005E+01  0.9703E+00



GROUP NO.  19     TOTAL NO. OF SAMPLES =     1816     28-APR-1988 12:19:30

T1 =   10.5000 SEC.     T2 =   16.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. 10 Cm. FWD. MID.


CH DESCRIPTION                            AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1732E+00  0.5044E-03 -0.1753E+00 -0.1717E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)         -0.5546E+00  0.1564E+00 -0.1143E+01 -0.1554E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)         -0.4280E+00  0.2336E+00 -0.1864E+01  0.6614E+00
 4 CENTRE THRUST (N)                     0.2953E+02  0.5533E+01  0.1846E+02  0.3840E+02
 5 CENTRE TORQUE (Nm)                    0.1728E+01  0.1908E+00  0.1279E+01  0.2300E+01
 6 SUCT. UPPER BENDING (Nm)              0.2961E+01  0.3236E+00  0.2264E+01  0.4087E+01
 7 SUCT. LOWER BENDING (Nm)              0.2545E+01  0.2670E+00  0.1437E+01  0.3445E+01
 8 SUCT. TORSION (Nm)                    0.1851E+01  0.1586E+00  0.7638E+00  0.2562E+01
 9 TOW FORCE (N)                        -0.3040E+02  0.8891E+01 -0.4663E+02 -0.1164E+02
10 PORT SHAFT SPEED (RPS)               -0.4942E-01  0.1692E-02 -0.6077E-01 -0.3108E-01
11 CENTRE SHAFT SPEED (RPS)              0.3421E+01  0.6145E-02  0.3409E+01  0.3449E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.1870E-02  0.3014E-02 -0.3437E-01  0.1995E-01
13 NOZZLE BN [#1 GAUGE] (Nm)            -0.6797E+01  0.1933E+00 -0.7280E+01 -0.6005E+01
14 NOZZLE BN [#2 GAUGE] (Nm)            -0.5038E+01  0.2308E+00 -0.5619E+01 -0.3656E+01
15 NOZZLE BN [#3 GAUGE] (Nm)            -0.5660E+01  0.2178E+00 -0.6566E+01 -0.4350E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)         -0.3199E+00  0.1760E+00 -0.1422E+01  0.2471E+00



GROUP NO.  19     TOTAL NO. OF SAMPLES =     1816     28-APR-1988 12:19:30

T1 =   21.0000 SEC.     T2 =   25.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. 10 Cm. FWD. MID.


CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                -0.1722E+00  0.1294E-03 -0.1733E+00 -0.1719E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)        -0.1175E+01  0.3454E+00 -0.2546E+01 -0.4413E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)        -0.8078E+00  0.3400E+00 -0.1565E+01 -0.2347E+00
 4 CENTRE THRUST (N)                    0.5056E+02  0.5639E+01  0.3812E+02  0.6068E+02
 5 CENTRE TORQUE (Nm)                   0.3136E+01  0.2757E+00  0.2480E+01  0.3771E+01
 6 SUCT. UPPER BENDING (Nm)             0.6683E+01  0.5627E+00  0.5225E+01  0.8113E+0
 7 SUCT. LOWER BENDING (Nm)             0.5518E+01  0.4672E+00  0.4432E+01  0.6704E+0
 8 SUCT. TORSION (Nm)                   0.4329E+01  0.1851E+00  0.3897E+01  0.4925E+01
 9 TOW FORCE (N)                       -0.7237E+02  0.1336E+02 -0.9640E+02 -0.4837E+02
10 PORT SHAFT SPEED (RPS)              -0.4837E-01  0.1704E-02 -0.5170E-01 -0.3190E-01
11 CENTRE SHAFT SPEED (RPS)             0.5124E+01  0.1343E-01  0.5098E+01  0.5144E+01
12 STRBRD. SHAFT SPEED (RPS)           -0.2195E-02  0.2616E-02 -0.3526E-01  0.3610E-03
13 NOZZLE BN [#1 GAUGE] (Nm)           -0.1277E+02  0.6234E+00 -0.1404E+02 -0.1146E+02
14 NOZZLE BN [#2 GAUGE] (Nm)           -0.1187E+02  0.6881E+00 -0.1326E+02 -0.1039E+02
15 NOZZLE BN [#3 GAUGE] (Nm)           -0.1323E+02  0.7246E+00 -0.1475E+02 -0.1168E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)        -0.6855E+00  0.3325E+00 -0.1227E+01 -0.5883E-01



GROUP NO.  19     TOTAL NO. OF SAMPLES =    1816     28-APR-1988 12:19:30

T1 =   29.0000 SEC.     T2 =   34.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. 10 Cm. FWD. MID.


CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)                -0.1701E+00  0.1912E-03 -0.1713E+00 -0.1691E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)        -0.2974E+01  0.7412E+00 -0.4132E+01 -0.1403E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)        -0.2022E+01  0.7739E+00 -0.3249E+01 -0.1260E+00
 4 CENTRE THRUST (N)                    0.1056E+03  0.5998E+01  0.8948E+02  0.1177E+03
 5 CENTRE TORQUE (Nm)                   0.6813E+01  0.2642E+00  0.6096E+01  0.7584E+01
 6 SUCT. UPPER BENDING (Nm)             0.1837E+02  0.4591E+00  0.1716E+02  0.1956E+02
 7 SUCT. LOWER BENDING (Nm)             0.1497E+02  0.3794E+00  0.1391E+02  0.1588E+02
 8 SUCT. TORSION (Nm)                   0.1213E+02  0.3898E+00  0.1052E+02  0.1402E+02
 9 TOW FORCE (N)                       -0.1775E+03  0.2278E+02 -0.2214E+03 -0.1362E+03
10 PORT SHAFT SPEED (RPS)              -0.4718E-01  0.1065E-02 -0.5582E-01 -0.3850E-01
11 CENTRE SHAFT SPEED (RPS)             0.7931E+01  0.1544E-01  0.7899E+01  0.7999E+01
12 STRBRD. SHAFT SPEED (RPS)           -0.1963E-02  0.2482E-02 -0.3170E-01  0.1461E-01
13 NOZZLE BN [#1 GAUGE] (Nm)           -0.2869E+02  0.1517E+01 -0.3243E+02 -0.2534E+02
14 NOZZLE BN [#2 GAUGE] (Nm)           -0.2983E+02  0.1638E+01 -0.3391E+02 -0.2630E+02
15 NOZZLE BN [#3 GAUGE] (Nm)           -0.3310E+02  0.1755E+01 -0.3745E+02 -0.2941E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)        -0.1806E+01  0.7370E+00 -0.3285E+01 -0.5039E+00
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GROUP NO.  20     TOTAL NO. OF SAMPLES =    3507     28-APR-1988 12:23:51

T1 =   21.0000 SEC.     T2 =   27.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 kts, AHEAD, Vm=0.266 M/S, CENTRE ONLY V/P, S.D.10 Cm FWD. MIOD


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1875E+00  0.3353E-03 -0.1889E+00 -0.1848E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.1407E+00  0.6785E-01 -0.7012E+00  0.2084E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.1377E+00  0.8433E-01 -0.7506E+00  0.6342E+00
 4 CENTRE THRUST (N)                  0.1323E+02  0.4869E+01  0.3305E+01  0.2081E+02
 5 CENTRE TORQUE (Nm)                 0.4650E+00  0.2246E+00  0.3009E-01  0.9332E+00
 6 SUCT. UPPER BENDING (Nm)           0.3580E+01  0.4359E+00  0.2318E+01  0.4430E+01
 7 SUCT. LOWER BENDING (Nm)           0.2774E+01  0.3318E+00  0.1842E+01  0.3463E+01
 8 SUCT. TORSION (Nm)                 0.1384E+01  0.2197E+00  0.4467E-01  0.1894E+01
 9 TOW FORCE (N)                      0.8541E+01  0.1341E+02 -0.2120E+02  0.3769E+02
10 PORT SHAFT SPEED (RPS)            -0.5082E-01  0.1208E-02 -0.5830E-01 -0.4180E-01
11 CENTRE SHAFT SPEED (RPS)           0.2944E+00  0.3383E-02  0.2687E+00  0.3162E+00
12 STRBRD. SHAFT SPEED (RPS)         -0.2006E-02  0.1922E-02 -0.2190E-01  0.7485E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.2539E+01  0.2973E+00 -0.3774E+01 -0.8340E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2521E+00  0.3259E+00 -0.9567E+00  0.1217E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.1542E+00  0.2894E+00 -0.1455E+01  0.1904E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.1210E+00  0.1547E+00 -0.1088E+01  0.1415E+01




GROUP NO.  20     TOTAL NO. OF SAMPLES =    3507     28-APR-1988 12:23:51

T1 =   31.0000 SEC.     T2 =   37.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 kts, AHEAD, Vm=0.266 M/S, CENTRE ONLY V/P, S.D.10 Cm FWD. MIOD


CH DESCRIPTION                          AVERAGE        RMS       MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1878E+00  0.1258E-03 -0.1887E+00 -0.1872E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.4855E+00  0.1179E+00 -0.1247E+01  0.5248E-01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.4336E+00  0.1168E+00 -0.1131E+01 -0.4459E-01
 4 CENTRE THRUST (N)                  0.2224E+02  0.5731E+01  0.1210E+02  0.3179E+02
 5 CENTRE TORQUE (Nm)                 0.1305E+01  0.2471E+00  0.7360E+00  0.1954E+01
 6 SUCT. UPPER BENDING (Nm)           0.7092E+01  0.1158E+01  0.4485E+01  0.1008E+02
 7 SUCT. LOWER BENDING (Nm)           0.5989E+01  0.9504E+00  0.3974E+01  0.8342E+01
 8 SUCT. TORSION (Nm)                 0.3564E+01  0.6154E+00  0.2254E+01  0.4745E+01
 9 TOW FORCE (N)                     -0.3586E+01  0.5392E+01 -0.1425E+02  0.6612E+01
10 PORT SHAFT SPEED (RPS)            -0.5104E-01  0.5815E-03 -0.5335E-01 -0.4757E-01
11 CENTRE SHAFT SPEED (RPS)           0.2637E+01  0.6402E-02  0.2600E+01  0.2671E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.2043E-02  0.8994E-03 -0.6763E-02  0.3923E-02
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13 NOZZLE BN [#1 GAUGE] (Nm)      -0.4383E+01  0.3412E+00 -0.5722E+01 -0.3455E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.1764E+01  0.4023E+00 -0.3621E+01 -0.3608E+00
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.2107E+01  0.3778E+00 -0.3528E+01 -0.1062E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)   -0.3964E+00  0.1436E+00 -0.1533E+01  0.1915E+00
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GROUP NO.  20     TOTAL NO. OF SAMPLES =    3507     28-APR-1988 12:23:51

T1 =   40.5000 SEC.     T2 =   47.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 kts, AHEAD, Vm=0.266 M/S, CENTRE ONLY V/P, S.D.10 Cm FWD. MIOD


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1873E+00  0.3121E-03 -0.1882E+00 -0.1835E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)   -0.1335E+01  0.2864E+00 -0.2001E+01 -0.8051E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.1078E+01  0.2993E+00 -0.1701E+01 -0.3161E+00
 4 CENTRE THRUST (N)               0.4589E+02  0.6028E+01  0.3263E+02  0.5614E+02
 5 CENTRE TORQUE (Nm)              0.2938E+01  0.2817E+00  0.2214E+01  0.3625E+01
 6 SUCT. UPPER BENDING (Nm)        0.1399E+02  0.1559E+01  0.1030E+02  0.1730E+02
 7 SUCT. LOWER BENDING (Nm)        0.1164E+02  0.1288E+01  0.8747E+01  0.1440E+02
 8 SUCT. TORSION (Nm)              0.7957E+01  0.7965E+00  0.6106E+01  0.9548E+01
 9 TOW FORCE (N)                  -0.3842E+02  0.1252E+02 -0.6119E+02 -0.1403E+02
10 PORT SHAFT SPEED (RPS)         -0.5087E-01  0.1723E-02 -0.6077E-01 -0.3273E-01
11 CENTRE SHAFT SPEED (RPS)        0.4799E+01  0.1287E-01  0.4769E+01  0.4823E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.2056E-02  0.1232E-02 -0.4982E-02  0.1461E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.1010E+02  0.5436E+00 -0.1206E+02 -0.8909E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.8251E+01  0.5870E+00 -0.9896E+01 -0.6951E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.9335E+01  0.6012E+00 -0.1111E+02 -0.7389E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)   -0.9801E+00  0.3090E+00 -0.2201E+01  0.1359E+00
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GROUP NO.  20     TOTAL NO. OF SAMPLES =    3507     28-APR-1988 12:23:51

T1 =   51.0000 SEC.     T2 =   57.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 kts, AHEAD, Vm=0.266 M/S, CENTRE ONLY V/P, S.D.10 Cm FWD. MIOD


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1847E+00  0.7732E-03 -0.1864E+00 -0.1836E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)   -0.2580E+01  0.5263E+00 -0.3846E+01 -0.1559E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.2008E+01  0.5651E+00 -0.3086E+01 -0.2347E+00
 4 CENTRE THRUST (N)               0.7733E+02  0.6618E+01  0.6131E+02  0.9020E+02
 5 CENTRE TORQUE (Nm)              0.5059E+01  0.3081E+00  0.4200E+01  0.5843E+01
 6 SUCT. UPPER BENDING (Nm)        0.2307E+02  0.1774E+01  0.1765E+02  0.2779E+02
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  7 SUCT. LOWER BENDING (Nm)         0.1905E+02  0.1453E+01  0.1470E+02  0.2291E+02
  8 SUCT. TORSION (Nm)               0.1391E+02  0.1132E+01  0.1050E+02  0.1712E+02
  9 TOW FORCE (N)                   -0.8870E+02  0.9527E+01 -0.1136E+03 -0.6641E+02
 10 PORT SHAFT SPEED (RPS)          -0.4979E-01  0.1816E-02 -0.7562E-01 -0.4015E-01
 11 CENTRE SHAFT SPEED (RPS)         0.6622E+01  0.1596E-01  0.6591E+01  0.6681E+01
 12 STRBRD. SHAFT SPEED (RPS)       -0.2180E-02  0.2557E-02 -0.2279E-01  0.2173E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)       -0.1855E+02  0.9238E+00 -0.2074E+02 -0.1631E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)       -0.1769E+02  0.1002E+01 -0.1992E+02 -0.1463E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)       -0.1987E+02  0.1046E+01 -0.2265E+02 -0.1732E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.1860E+01  0.5399E+00 -0.2924E+01 -0.8098E+00


GROUP NO.  20     TOTAL NO. OF SAMPLES =     3507     28-APR-1988 12:23:51

T1 =    61.0000 SEC.      T2 =    68.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 kts, AHEAD, Vm=0.266 M/S, CENTRE ONLY V/P, S.D.10 Cm FWD. MIOD


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)            -0.1818E+00  0.3749E-03 -0.1831E+00 -0.1796E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)    -0.3260E+01  0.6701E+00 -0.4625E+01 -0.1767E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)    -0.2505E+01  0.7070E+00 -0.3900E+01 -0.5876E+00
  4 CENTRE THRUST (N)                0.9646E+02  0.6983E+01  0.7576E+02  0.1111E+03
  5 CENTRE TORQUE (Nm)               0.6104E+01  0.3189E+00  0.5318E+01  0.7120E+01
  6 SUCT. UPPER BENDING (Nm)         0.2899E+02  0.7751E+00  0.2638E+02  0.3093E+02
  7 SUCT. LOWER BENDING (Nm)         0.2390E+02  0.6049E+00  0.2201E+02  0.2550E+02
  8 SUCT. TORSION (Nm)               0.1781E+02  0.4992E+00  0.1615E+02  0.1903E+02
  9 TOW FORCE (N)                   -0.1198E+03  0.9493E+01 -0.1355E+03 -0.9944E+02
 10 PORT SHAFT SPEED (RPS)          -0.4845E-01  0.1390E-02 -0.5912E-01 -0.3850E-01
 11 CENTRE SHAFT SPEED (RPS)         0.7510E+01  0.1500E-01  0.7477E+01  0.7545E+01
 12 STRBRD. SHAFT SPEED (RPS)       -0.2062E-02  0.7495E-03 -0.6763E-02  0.3923E-02
 13 NOZZLE BN [#1 GAUGE] (Nm)       -0.2384E+02  0.2363E+01 -0.2945E+02 -0.1950E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)       -0.2371E+02  0.2580E+01 -0.2886E+02 -0.1905E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)       -0.2649E+02  0.2816E+01 -0.3198E+02 -0.2158E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.2345E+01  0.6772E+00 -0.3563E+01 -0.9489E+00


GROUP NO.  21     TOTAL NO. OF SAMPLES =     1874     28-APR-1988 12:54:37

T1 =     2.5000 SEC.      T2 =     6.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM
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 1 CARRIAGE SPEED (M/S)              -0.1530E+00  0.1959E-03 -0.1546E+00 -0.1526E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.2123E+01  0.4044E-01  0.1950E+01  0.2391E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.2136E+01  0.1679E+00  0.1096E+01  0.3051E+01
 4 CENTRE THRUST (N)                  0.1662E+02  0.5349E+01  0.7125E+01  0.2539E+02
 5 CENTRE TORQUE (Nm)                 0.6029E+00  0.1388E+00  0.2965E+00  0.8952E+00
 6 SUCT. UPPER BENDING (Nm)          -0.1196E+00  0.6059E-01 -0.3202E+00  0.1853E+00
 7 SUCT. LOWER BENDING (Nm)          -0.1120E+00  0.8735E-01 -0.9159E+00  0.3876E+00
 8 SUCT. TORSION (Nm)                 0.8061E-02  0.1076E+00 -0.1006E+01  0.5354E+00
 9 TOW FORCE (N)                     -0.7166E+01  0.6222E+01 -0.1947E+02  0.1118E+02
10 PORT SHAFT SPEED (RPS)            -0.4435E-01  0.1412E-02 -0.5252E-01 -0.3768E-01
11 CENTRE SHAFT SPEED (RPS)           0.2716E+00  0.2694E-02  0.2586E+00  0.2840E+00
12 STRBRD. SHAFT SPEED (RPS)         -0.2120E-02  0.9521E-03 -0.6763E-02  0.3032E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.1255E+01  0.1551E+00 -0.2392E+01 -0.7986E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2388E+01  0.1256E+00  0.2023E+01  0.3110E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.3204E+01  0.1423E+00  0.2762E+01  0.4299E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.2196E+01  0.5498E-01  0.1749E+01  0.2472E+01



GROUP NO.  21     TOTAL NO. OF SAMPLES =     1874     28-APR-1988 12:54:37

T1 =   10.0000 SEC.     T2 =   16.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                          AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1533E+00  0.2669E-03 -0.1546E+00 -0.1512E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.3511E+01  0.1601E+00  0.3093E+01  0.4886E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.3586E+01  0.1544E+00  0.2698E+01  0.4028E+01
 4 CENTRE THRUST (N)                  0.3434E+02  0.5893E+01  0.2264E+02  0.4437E+02
 5 CENTRE TORQUE (Nm)                 0.1222E+01  0.2319E+00  0.6564E+00  0.1819E+01
 6 SUCT. UPPER BENDING (Nm)          -0.1214E+00  0.1653E+00 -0.7896E+00  0.4020E+00
 7 SUCT. LOWER BENDING (Nm)           0.2766E+00  0.1148E+00 -0.1760E+00  0.8456E+00
 8 SUCT. TORSION (Nm)                 0.3938E-01  0.1397E+00 -0.5433E+00  0.1203E+01
 9 TOW FORCE (N)                     -0.1930E+02  0.1405E+02 -0.4793E+02  0.1205E+02
10 PORT SHAFT SPEED (RPS)            -0.4460E-01  0.7832E-03 -0.5170E-01 -0.4180E-01
11 CENTRE SHAFT SPEED (RPS)           0.3013E+01  0.9543E-02  0.2971E+01  0.3031E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.2228E-02  0.1466E-02 -0.6763E-02  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.1682E+01  0.5363E+00 -0.4022E+01 -0.1256E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          0.1969E+01  0.5666E+00  0.5156E+00  0.3250E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.2784E+01  0.6551E+00  0.1154E+01  0.4728E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.3625E+01  0.2189E+00  0.2472E+01  0.5115E+01



GROUP NO.  21     TOTAL NO. OF SAMPLES =     1874     28-APR-1988 12:54:37

T1 =   19.5000 SEC.     T2 =   26.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.
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CH DESCRIPTION                        AVERAGE       RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1535E+00  0.1802E-03 -0.1543E+00 -0.1511E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.7707E+01  0.5662E+00  0.6420E+01  0.9356E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.8019E+01  0.6078E+00  0.6662E+01  0.1008E+02
 4 CENTRE THRUST (N)                 0.7568E+02  0.7125E+01  0.5865E+02  0.9135E+02
 5 CENTRE TORQUE (Nm)                0.3724E+01  0.3748E+00  0.2819E+01  0.4594E+01
 6 SUCT. UPPER BENDING (Nm)          0.2350E+00  0.9777E+00 -0.1927E+01  0.2207E+01
 7 SUCT. LOWER BENDING (Nm)          0.5411E+00  0.2757E+00 -0.5107E+00  0.1251E+01
 8 SUCT. TORSION (Nm)               -0.9448E-01  0.1888E+00 -0.9029E+00  0.6382E+00
 9 TOW FORCE (N)                    -0.5232E+02  0.1832E+02 -0.8705E+02 -0.1642E+02
10 PORT SHAFT SPEED (RPS)           -0.4495E-01  0.2258E-02 -0.7891E-01 -0.3438E-01
11 CENTRE SHAFT SPEED (RPS)          0.5551E+01  0.2289E-01  0.5505E+01  0.5598E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2401E-02  0.2401E-02 -0.3704E-01  0.1728E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.2984E+01  0.4101E+01 -0.1072E+02  0.4018E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.3679E+00  0.4556E+01 -0.8249E+01  0.8123E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.1219E+01  0.4922E+01 -0.8175E+01  0.9553E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.7959E+01  0.6191E+00  0.6394E+01  0.9176E+01




GROUP NO.  21     TOTAL NO. OF SAMPLES =    1874     28-APR-1988 12:54:37

T1 =   28.0000 SEC.     T2 =   35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                        AVERAGE       RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1533E+00  0.2032E-03 -0.1546E+00 -0.1517E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1195E+02  0.8517E+00  0.9798E+01  0.1393E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.1248E+02  0.8411E+00  0.1035E+02  0.1454E+02
 4 CENTRE THRUST (N)                 0.1206E+03  0.9178E+01  0.9577E+02  0.1389E+03
 5 CENTRE TORQUE (Nm)                0.6707E+01  0.4590E+00  0.5494E+01  0.7951E+01
 6 SUCT. UPPER BENDING (Nm)          0.3519E+00  0.3021E+01 -0.6296E+01  0.6288E+01
 7 SUCT. LOWER BENDING (Nm)          0.6551E+00  0.2091E+01 -0.3294E+01  0.4281E+01
 8 SUCT. TORSION (Nm)               -0.8517E-01  0.6271E+00 -0.1365E+01  0.1640E+01
 9 TOW FORCE (N)                    -0.8790E+02  0.4290E+01 -0.9835E+02 -0.8053E+02
10 PORT SHAFT SPEED (RPS)           -0.4511E-01  0.1536E-02 -0.6902E-01 -0.3850E-01
11 CENTRE SHAFT SPEED (RPS)          0.7333E+01  0.2469E-01  0.7282E+01  0.7401E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2102E-02  0.1820E-02 -0.7653E-02  0.2618E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4089E+01  0.2663E+01 -0.1100E+02  0.1468E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.7872E+00  0.2930E+01 -0.8389E+01  0.5248E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2046E+00  0.3177E+01 -0.7996E+01  0.6551E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1231E+02  0.7939E+00  0.1012E+02  0.1418E+02
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GROUP NO.  22     TOTAL NO. OF SAMPLES =     2343     28-APR-1988 12:58:31

T1 =     1.0000 SEC.      T2 =    10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1421E+00  0.1137E-02 -0.1461E+00 -0.1392E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.2863E+01  0.1327E+00  0.2158E+01  0.3639E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.2856E+01  0.1590E+00  0.2155E+01  0.4381E+01
 4 CENTRE THRUST (N)                  0.1308E+02  0.4372E+01  0.5892E+01  0.2153E+02
 5 CENTRE TORQUE (Nm)                 0.3825E+00  0.2411E+00 -0.5988E-01  0.8710E+00
 6 SUCT. UPPER BENDING (Nm)           0.1017E+01  0.2925E+00  0.3117E+00  0.2298E+01
 7 SUCT. LOWER BENDING (Nm)           0.6653E+00  0.1426E+00 -0.2465E+00  0.1497E+01
 8 SUCT. TORSION (Nm)                -0.1753E+00  0.8459E-01 -0.6461E+00  0.6638E+00
 9 TOW FORCE (N)                      0.4445E+01  0.7429E+01 -0.1316E+02  0.2487E+02
10 PORT SHAFT SPEED (RPS)            -0.3926E-01  0.2204E-02 -0.6242E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)           0.1088E+00  0.2683E-02  0.8402E-01  0.1213E+00
12 STRBRD. SHAFT SPEED (RPS)         -0.1228E-02  0.2611E-02 -0.1834E-01  0.2084E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.1698E+01  0.3449E+00 -0.3526E+01 -0.6923E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2856E+01  0.4343E+00  0.1147E+01  0.4547E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.3578E+01  0.3861E+00  0.1761E+01  0.5050E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.2862E+01  0.1346E+00  0.2027E+01  0.3891E+01
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GROUP NO.  22     TOTAL NO. OF SAMPLES =     2343     28-APR-1988 12:58:31

T1 =    14.0000 SEC.      T2 =    21.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                           AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1365E+00  0.9340E-03 -0.1395E+00 -0.1344E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.3584E+01  0.2977E+00  0.3015E+01  0.4237E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.3602E+01  0.3256E+00  0.2589E+01  0.4571E+01
 4 CENTRE THRUST (N)                  0.2629E+02  0.5625E+01  0.1425E+02  0.3569E+02
 5 CENTRE TORQUE (Nm)                 0.1087E+01  0.3133E+00  0.3761E+00  0.1829E+01
 6 SUCT. UPPER BENDING (Nm)           0.7455E+00  0.8092E+00 -0.9701E+00  0.2442E+01
 7 SUCT. LOWER BENDING (Nm)           0.6139E+00  0.5904E+00 -0.6693E+00  0.1762E+01
 8 SUCT. TORSION (Nm)                -0.1682E+00  0.2018E+00 -0.1571E+01  0.6895E+00
 9 TOW FORCE (N)                     -0.4046E+01  0.9354E+01 -0.2099E+02  0.1270E+02
10 PORT SHAFT SPEED (RPS)            -0.3591E-01  0.1425E-02 -0.4675E-01 -0.3190E-01
11 CENTRE SHAFT SPEED (RPS)           0.2485E+01  0.1188E-01  0.2463E+01  0.2538E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1691E-02  0.1638E-02 -0.1567E-01  0.9266E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.1836E+01  0.5079E+00 -0.3526E+01 -0.7986E+00
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2245E+01  0.6150E+00  0.7260E+00  0.3776E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.3003E+01  0.6093E+00  0.1511E+01  0.4406E+01
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16 NOZZLE TORSION [ #1 Gg] (Nm)   0.3587E+01  0.3470E+00  0.1638E+01  0.5059E+01


GROUP NO.  22     TOTAL NO. OF SAMPLES =    2343     28-APR-1988 12:58:31

T1 =    24.0000 SEC.      T2 =    30.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                      AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1343E+00  0.8487E-03 -0.1364E+00 -0.1319E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.5616E+01  0.3996E+00  0.4522E+01  0.6757E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.5738E+01  0.4124E+00  0.4626E+01  0.7477E+01
 4 CENTRE THRUST (N)               0.5019E+02  0.6095E+01  0.3529E+02  0.6064E+02
 5 CENTRE TORQUE (Nm)              0.2505E+01  0.3457E+00  0.1618E+01  0.3400E+01
 6 SUCT. UPPER BENDING (Nm)        0.7684E+00  0.5577E+00 -0.6090E+00  0.1900E+01
 7 SUCT. LOWER BENDING (Nm)        0.7198E+00  0.3571E+00 -0.2641E+00  0.1497E+01
 8 SUCT. TORSION (Nm)             -0.1420E+00  0.2336E+00 -0.6461E+00  0.3556E+00
 9 TOW FORCE (N)                  -0.2063E+02  0.7473E+01 -0.4076E+02 -0.1428E+01
10 PORT SHAFT SPEED (RPS)         -0.3417E-01  0.1697E-02 -0.3850E-01 -0.1706E-01
11 CENTRE SHAFT SPEED (RPS)        0.4350E+01  0.1400E-01  0.4313E+01  0.4374E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.1553E-02  0.1385E-02 -0.6763E-02  0.1372E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.2117E+01  0.9981E+00 -0.4234E+01  0.4765E+00
14 NOZZLE BN [#2 GAUGE] (Nm)       0.2141E+01  0.1148E+01 -0.3608E+00  0.5248E+01
15 NOZZLE BN [#3 GAUGE] (Nm)       0.2964E+01  0.1293E+01  0.2245E+00  0.6229E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.5682E+01  0.3954E+00  0.4586E+01  0.6923E+01


GROUP NO.  22     TOTAL NO. OF SAMPLES =    2343     28-APR-1988 12:58:31

T1 =    33.0000 SEC.      T2 =    37.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                      AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1324E+00  0.1076E-02 -0.1368E+00 -0.1287E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.1154E+02  0.1174E+01  0.9512E+01  0.1383E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.1192E+02  0.1182E+01  0.9975E+01  0.1424E+02
 4 CENTRE THRUST (N)               0.1113E+03  0.8154E+01  0.8992E+02  0.1300E+03
 5 CENTRE TORQUE (Nm)              0.6178E+01  0.4976E+00  0.4982E+01  0.7221E+01
 6 SUCT. UPPER BENDING (Nm)        0.1140E+01  0.3456E+01 -0.5285E+01  0.7407E+01
 7 SUCT. LOWER BENDING (Nm)        0.1160E+01  0.2404E+01 -0.3223E+01  0.5144E+01
 8 SUCT. TORSION (Nm)             -0.1798E+00  0.7401E+00 -0.1596E+01  0.1126E+01
 9 TOW FORCE (N)                  -0.6430E+02  0.1734E+02 -0.9509E+02 -0.3707E+02
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10 PORT SHAFT SPEED (RPS)           -0.3264E-01  0.2011E-02 -0.3933E-01 -0.2283E-01
11 CENTRE SHAFT SPEED (RPS)          0.7154E+01  0.2262E-01  0.7103E+01  0.7209E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1522E-02  0.9324E-03 -0.8544E-02  0.3032E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.2750E+01  0.2654E+01 -0.7918E+01  0.3416E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1498E+01  0.2870E+01 -0.4182E+01  0.7878E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2497E+01  0.3077E+01 -0.3636E+01  0.9374E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1179E+02  0.1144E+01  0.9954E+01  0.1407E+02


GROUP NO.  22     TOTAL NO. OF SAMPLES =     2343     28-APR-1988 12:58:31

T1 =    42.5000 SEC.     T2 =    45.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D. TOP FWD.


CH DESCRIPTION                         AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1309E+00  0.6273E-03 -0.1321E+00 -0.1291E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1596E+02  0.6167E+00  0.1450E+02  0.1718E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.1656E+02  0.6657E+00  0.1511E+02  0.1796E+02
 4 CENTRE THRUST (N)                 0.1511E+03  0.9874E+01  0.1234E+03  0.1718E+03
 5 CENTRE TORQUE (Nm)                0.8504E+01  0.1071E+01  0.5709E+01  0.1129E+02
 6 SUCT. UPPER BENDING (Nm)          0.2217E+01  0.9019E+00 -0.8546E-01  0.4717E+01
 7 SUCT. LOWER BENDING (Nm)          0.2071E+01  0.5937E+00  0.5462E+00  0.3382E+01
 8 SUCT. TORSION (Nm)               -0.3617E+00  0.2782E+00 -0.1622E+01  0.5097E+00
 9 TOW FORCE (N)                    -0.9270E+02  0.1136E+02 -0.1120E+03 -0.7293E+02
10 PORT SHAFT SPEED (RPS)           -0.3156E-01  0.1900E-02 -0.4592E-01 -0.2118E-01
11 CENTRE SHAFT SPEED (RPS)          0.8448E+01  0.4524E-01  0.8345E+01  0.8561E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.2014E-02  0.3498E-02 -0.3437E-01  0.4813E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.3845E+01  0.2700E+01 -0.9759E+01  0.3027E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.6066E+00  0.2914E+01 -0.5865E+01  0.7842E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.1809E+01  0.3200E+01 -0.5566E+01  0.9410E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1632E+02  0.6754E+00  0.1479E+02  0.1760E+02


GROUP NO.  23     TOTAL NO. OF SAMPLES =     2186     28-APR-1988 13:09:41

T1 =     1.0000 SEC.     T2 =     7.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. TOP AFT


CH DESCRIPTION                         AVERAGE        RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1331E+00  0.6457E-03 -0.1347E+00 -0.1293E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1839E+01  0.1062E+00 -0.3144E+01 -0.1481E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1854E+01  0.7167E-01 -0.2190E+01 -0.1266E+01
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  4 CENTRE THRUST (N)                 0.1579E+02  0.5572E+01  0.5971E+01  0.2451E+02
  5 CENTRE TORQUE (Nm)               -0.1981E+00  0.1337E+00 -0.5063E+00  0.7853E-01
  6 SUCT. UPPER BENDING (Nm)         -0.1104E+00  0.5682E-01 -0.6993E+00  0.5896E-01
  7 SUCT. LOWER BENDING (Nm)          0.5225E-01  0.8093E-01 -0.6783E+00  0.6780E+00
  8 SUCT. TORSION (Nm)               -0.3122E-01  0.9966E-01 -0.6375E+00  0.1289E+01
  9 TOW FORCE (N)                    -0.2313E+01  0.3577E+01 -0.1099E+02  0.5526E+01
 10 PORT SHAFT SPEED (RPS)           -0.1418E-01  0.1940E-02 -0.2530E-01  0.6862E-02
 11 CENTRE SHAFT SPEED (RPS)         -0.4192E+00  0.3798E-02 -0.4345E+00 -0.3836E+00
 12 STRBRD. SHAFT SPEED (RPS)        -0.1412E-02  0.2428E-02 -0.1923E-01  0.2440E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)        -0.5970E+01  0.2529E+00 -0.7103E+01 -0.3774E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)        -0.1452E+01  0.2165E+00 -0.3481E+01  0.3053E+00
 15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2195E+01  0.1524E+00 -0.2992E+01 -0.2044E+00
 16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1716E+01  0.9113E-01 -0.2228E+01 -0.3370E+00



GROUP NO.  23     TOTAL NO. OF SAMPLES =     2186     28-APR-1988 13:09:41

T1 =    10.5000 SEC.      T2 =    16.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. TOP AFT


CH DESCRIPTION                         AVERAGE       RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)             -0.1328E+00  0.5059E-03 -0.1347E+00 -0.1317E+00
  2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.4047E+01  0.4567E+00 -0.5041E+01 -0.2910E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.4234E+01  0.4437E+00 -0.5204E+01 -0.3113E+01
  4 CENTRE THRUST (N)                -0.1921E+02  0.6488E+01 -0.2976E+02 -0.5448E+01
  5 CENTRE TORQUE (Nm)               -0.2047E+01  0.2911E+00 -0.2825E+01 -0.1288E+01
  6 SUCT. UPPER BENDING (Nm)          0.8718E+00  0.2314E+00  0.3117E+00  0.1467E+01
  7 SUCT. LOWER BENDING (Nm)          0.1006E+01  0.1594E+00  0.1320E+00  0.1541E+01
  8 SUCT. TORSION (Nm)               -0.2439E+00  0.1782E+00 -0.1768E+01  0.1237E+01
  9 TOW FORCE (N)                     0.2530E+02  0.1057E+02  0.4656E+01  0.4747E+02
 10 PORT SHAFT SPEED (RPS)           -0.1410E-01  0.1739E-02 -0.2530E-01  0.6862E-02
 11 CENTRE SHAFT SPEED (RPS)         -0.3897E+01  0.1278E-01 -0.3918E+01 -0.3844E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.1378E-02  0.1821E-02 -0.1389E-01  0.1817E-01
 13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4201E+01  0.1094E+01 -0.6465E+01 -0.1790E+01
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.8120E+00  0.1228E+01 -0.1658E+01  0.3566E+01
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.1478E+00  0.1398E+01 -0.2635E+01  0.3298E+01
 16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.4089E+01  0.4394E+00 -0.5232E+01 -0.2979E+01



GROUP NO.  23     TOTAL NO. OF SAMPLES =     2186     28-APR-1988 13:09:41

T1 =    19.5000 SEC.      T2 =    25.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. TOP AFT
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CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1322E+00  0.6635E-03 -0.1351E+00 -0.1308E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.6070E+01  0.3949E+00 -0.7848E+01 -0.5301E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.6375E+01  0.4040E+00 -0.7457E+01 -0.5013E+01
 4 CENTRE THRUST (N)                  -0.5003E+02  0.7291E+01 -0.6378E+02 -0.3358E+02
 5 CENTRE TORQUE (Nm)                 -0.3730E+01  0.3828E+00 -0.4621E+01 -0.2610E+01
 6 SUCT. UPPER BENDING (Nm)            0.1823E+01  0.5202E+00  0.5103E+00  0.3182E+01
 7 SUCT. LOWER BENDING (Nm)            0.1727E+01  0.3639E+00  0.9673E-01  0.2492E+01
 8 SUCT. TORSION (Nm)                 -0.4446E+00  0.1855E+00 -0.2256E+01 -0.7242E-01
 9 TOW FORCE (N)                       0.4760E+02  0.6418E+01  0.3312E+02  0.6116E+02
10 PORT SHAFT SPEED (RPS)             -0.1385E-01  0.1948E-02 -0.2118E-01  0.1511E-01
11 CENTRE SHAFT SPEED (RPS)           -0.5339E+01  0.1883E-01 -0.5376E+01 -0.5299E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.1651E-02  0.1988E-02 -0.1923E-01  0.7485E-02
13 NOZZLE BN [#1 GAUGE] (Nm)          -0.2606E+01  0.9515E+00 -0.5368E+01  0.5119E+00
14 NOZZLE BN [#2 GAUGE] (Nm)           0.2700E+01  0.1031E+01 -0.4309E+00  0.4898E+01
15 NOZZLE BN [#3 GAUGE] (Nm)           0.2115E+01  0.1150E+01 -0.1384E+01  0.5550E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)       -0.6208E+01  0.3966E+00 -0.7318E+01 -0.4593E+01



GROUP NO.  23     TOTAL NO. OF SAMPLES =     2186     28-APR-1988 13:09:41

T1 =    29.0000 SEC.      T2 =    34.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. TOP AFT


CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1320E+00  0.4844E-03 -0.1334E+00 -0.1294E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.7315E+01  0.5916E+00 -0.9433E+01 -0.6055E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.7718E+01  0.6078E+00 -0.9113E+01 -0.6507E+01
 4 CENTRE THRUST (N)                  -0.6658E+02  0.7986E+01 -0.8267E+02 -0.4802E+02
 5 CENTRE TORQUE (Nm)                 -0.4686E+01  0.4614E+00 -0.5655E+01 -0.3486E+01
 6 SUCT. UPPER BENDING (Nm)            0.2356E+01  0.1812E+01 -0.1277E+01  0.5836E+01
 7 SUCT. LOWER BENDING (Nm)            0.2149E+01  0.5196E+00  0.1030E+01  0.3215E+01
 8 SUCT. TORSION (Nm)                 -0.5435E+00  0.2589E+00 -0.2024E+01  0.1083E+01
 9 TOW FORCE (N)                       0.6046E+02  0.8350E+01  0.4682E+02  0.7463E+02
10 PORT SHAFT SPEED (RPS)             -0.1421E-01  0.1335E-02 -0.2530E-01 -0.1211E-01
11 CENTRE SHAFT SPEED (RPS)           -0.5995E+01  0.2194E-01 -0.6047E+01 -0.5957E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.1377E-02  0.9693E-03 -0.3201E-02  0.4813E-02
13 NOZZLE BN [#1 GAUGE] (Nm)          -0.1218E+01  0.4083E+01 -0.7918E+01  0.5931E+01
14 NOZZLE BN [#2 GAUGE] (Nm)           0.4063E+01  0.4406E+01 -0.3130E+01  0.1205E+02
15 NOZZLE BN [#3 GAUGE] (Nm)           0.3470E+01  0.4724E+01 -0.4279E+01  0.1202E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)       -0.7505E+01  0.6288E+00 -0.8793E+01 -0.5622E+01



GROUP NO.  23     TOTAL NO. OF SAMPLES =     2186     28-APR-1988 13:09:41

T1 =    38.0000 SEC.      T2 =    41.5000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. TOP AFT


CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1313E+00  0.5534E-03 -0.1325E+00 -0.1275E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.9750E+01  0.7610E+00 -0.1128E+02 -0.7848E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.1030E+02  0.7683E+00 -0.1186E+02 -0.8516E+01
 4 CENTRE THRUST (N)                 -0.9819E+02  0.9564E+01 -0.1200E+03 -0.7885E+02
 5 CENTRE TORQUE (Nm)                -0.6398E+01  0.5760E+00 -0.7853E+01 -0.4884E+01
 6 SUCT. UPPER BENDING (Nm)           0.3323E+01  0.1192E+01  0.7089E+00  0.5602E+01
 7 SUCT. LOWER BENDING (Nm)           0.2816E+01  0.3953E+00  0.1206E+01  0.3761E+01
 8 SUCT. TORSION (Nm)                -0.7532E+00  0.2453E+00 -0.1408E+01  0.8522E+00
 9 TOW FORCE (N)                      0.8754E+02  0.5577E+01  0.7833E+02  0.1003E+03
10 PORT SHAFT SPEED (RPS)            -0.1384E-01  0.3348E-02 -0.3933E-01  0.1593E-01
11 CENTRE SHAFT SPEED (RPS)          -0.7016E+01  0.2305E-01 -0.7082E+01 -0.6977E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1400E-02  0.1714E-02 -0.1211E-01  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          0.9331E+00  0.1771E+01 -0.2357E+01  0.4868E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          0.5998E+01  0.1950E+01  0.2268E+01  0.1030E+02
15 NOZZLE BN [#3 GAUGE] (Nm)          0.5450E+01  0.2142E+01  0.1261E+01  0.1020E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.1010E+02  0.7510E+00 -0.1166E+02 -0.8347E+01



GROUP NO.  24     TOTAL NO. OF SAMPLES =     2586     28-APR-1988 13:15:23

T1 =    1.0000 SEC.     T2 =    9.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/S, ASTERN, CENTRE ONLY, V/P S.D.TOP AFT


CH DESCRIPTION                          AVERAGE        RMS         MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1178E+00  0.3932E-03 -0.1200E+00 -0.1154E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.2004E+01  0.9731E-01 -0.3404E+01 -0.1377E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.2019E+01  0.1723E+00 -0.3303E+01  0.3084E+00
 4 CENTRE THRUST (N)                  0.1412E+02  0.5760E+01  0.4101E+01  0.2336E+02
 5 CENTRE TORQUE (Nm)                -0.1596E+00  0.1358E+00 -0.4751E+00  0.1754E+00
 6 SUCT. UPPER BENDING (Nm)          -0.1246E+00  0.1217E+00 -0.1205E+01  0.1196E+01
 7 SUCT. LOWER BENDING (Nm)           0.2552E-01  0.1217E+00 -0.9778E+00  0.5900E+00
 8 SUCT. TORSION (Nm)                -0.9792E-01  0.1238E+00 -0.9457E+00  0.1546E+01
 9 TOW FORCE (N)                     -0.6824E+02  0.1356E+01 -0.7901E+02 -0.6010E+02
10 PORT SHAFT SPEED (RPS)            -0.1355E-01  0.1327E-02 -0.2530E-01 -0.5510E-02
11 CENTRE SHAFT SPEED (RPS)          -0.8278E+00  0.3520E-02 -0.8717E+00 -0.8123E+00
12 STRBRD. SHAFT SPEED (RPS)         -0.1520E-02  0.2153E-02 -0.2368E-01  0.1550E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.6391E+01  0.1420E+00 -0.6890E+01 -0.5580E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         -0.1337E+01  0.9303E-01 -0.1798E+01 -0.9567E+00
15 NOZZLE BN [#3 GAUGE] (Nm)         -0.1981E+01  0.2401E+00 -0.5030E+01  0.5104E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.1854E+01  0.1356E+00 -0.3814E+01 -0.1283E+01
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GROUP NO.  24     TOTAL NO. OF SAMPLES =    2586     28-APR-1988 13:15:23

T1 =    14.5000 SEC.      T2 =    19.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/S, ASTERN, CENTRE ONLY, V/P S.D.TOP AFT


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1171E+00  0.4100E-03 -0.1179E+00 -0.1125E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.2559E+01  0.3267E+00 -0.3170E+01 -0.1715E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.2569E+01  0.3381E+00 -0.3737E+01 -0.2054E+01
 4 CENTRE THRUST (N)                  0.1443E+02  0.5822E+01  0.5295E+01  0.2431E+02
 5 CENTRE TORQUE (Nm)                -0.1457E+00  0.1426E+00 -0.[illegible]063E+00  0.2031E+00
 6 SUCT. UPPER BENDING (Nm)          -0.1228E+01  0.2832E+01 -0.5502E+01  0.2930E+01
 7 SUCT. LOWER BENDING (Nm)          -0.7315E+00  0.2303E+01 -0.4149E+01  0.2704E+01
 8 SUCT. TORSION (Nm)                 0.1675E+00  0.9107E+00 -0.1305E+01  0.2265E+01
 9 TOW FORCE (N)                     -0.1148E+02  0.1929E+02 -0.4793E+02  0.3356E+02
10 PORT SHAFT SPEED (RPS)            -0.1330E-01  0.2160E-02 -0.3025E-01  0.5212E-02
11 CENTRE SHAFT SPEED (RPS)          -0.8283E+00  0.2693E-02 -0.8445E+00 -0.8140E+00
12 STRBRD. SHAFT SPEED (RPS)         -0.1260E-02  0.1791E-02 -0.7653E-02  0.1728E-01
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.6908E+01  0.4553E+00 -0.9051E+01 -0.6182E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         -0.2107E+01  0.4943E+00 -0.3516E+01  0.2001E+00
15 NOZZLE BN [#3 GAUGE] (Nm)         -0.2878E+01  0.5175E+00 -0.4243E+01 -0.1849E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.2386E+01  0.3256E+00 -0.3007E+01 -0.1310E+01
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GROUP NO.  24     TOTAL NO. OF SAMPLES =    2586     28-APR-1988 13:15:23

T1 =    24.5000 SEC.      T2 =    29.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/S, ASTERN, CENTRE ONLY, V/P S.D.TOP AFT


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1166E+00  0.3293E-03 -0.1179E+00 -0.1159E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.4689E+01  0.4463E+00 -0.5899E+01 -0.3664E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.4798E+01  0.4374E+00 -0.5882E+01 -0.3737E+01
 4 CENTRE THRUST (N)                 -0.1517E+02  0.6175E+01 -0.2669E+02 -0.2702E+01
 5 CENTRE TORQUE (Nm)                -0.1822E+01  0.2921E+00 -0.2479E+01 -0.1067E+01
 6 SUCT. UPPER BENDING (Nm)          -0.3361E+00  0.2416E+01 -0.3949E+01  0.3598E+01
 7 SUCT. LOWER BENDING (Nm)           0.1486E+00  0.1936E+01 -0.2792E+01  0.3461E+01
 8 SUCT. TORSION (Nm)                -0.1132E+00  0.7750E+00 -0.1485E+01  0.1160E+01
 9 TOW FORCE (N)                      0.2318E+01  0.1235E+02 -0.1816E+02  0.2421E+02
10 PORT SHAFT SPEED (RPS)            -0.1322E-01  0.8518E-03 -0.1706E-01 -0.6335E-02
11 CENTRE SHAFT SPEED (RPS)          -0.3779E+01  0.1258E-01 -0.3827E+01 -0.3747E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1349E-02  0.2166E-02 -0.4982E-02  0.2886E-01
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13 NOZZLE BN [#1 GAUGE] (Nm)      -0.6064E+01  0.1009E+01 -0.8909E+01 -0.4057E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.1454E+01  0.1154E+01 -0.4673E+01  0.1497E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.2348E+01  0.1285E+01 -0.6030E+01  0.8153E-01
16 NOZZLE TORSION [ #1 Gg] (Nm)  -0.4591E+01  0.4305E+00 -0.5622E+01 -0.3285E+01


GROUP NO.  24     TOTAL NO. OF SAMPLES =    2586     28-APR-1988 13:15:23

T1 =    32.5000 SEC.      T2 =    40.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/S, ASTERN, CENTRE ONLY, V/P S.D.TOP AFT


CH DESCRIPTION                      AVERAGE        RMS         MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1168E+00  0.3004E-03 -0.1197E+00 -0.1161E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)  -0.6255E+01  0.4896E+00 -0.7484E+01 -0.4963E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)  -0.6443E+01  0.5069E+00 -0.7674E+01 -0.4823E+01
 4 CENTRE THRUST (N)              -0.3687E+02  0.7115E+01 -0.5112E+02 -0.2100E+02
 5 CENTRE TORQUE (Nm)             -0.3022E+01  0.3631E+00 -0.3894E+01 -0.1890E+01
 6 SUCT. UPPER BENDING (Nm)        0.1417E+00  0.2736E+01 -0.4400E+01  0.4627E+01
 7 SUCT. LOWER BENDING (Nm)        0.3947E+00  0.2178E+01 -0.2986E+01  0.3884E+01
 8 SUCT. TORSION (Nm)             -0.2249E+00  0.8756E+00 -0.1665E+01  0.2547E+01
 9 TOW FORCE (N)                   0.1566E+02  0.1286E+02 -0.2950E+01  0.4030E+02
10 PORT SHAFT SPEED (RPS)         -0.1362E-01  0.8987E-03 -0.1953E-01 -0.8809E-02
11 CENTRE SHAFT SPEED (RPS)       -0.4880E+01  0.1802E-01 -0.4913E+01 -0.4820E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.1309E-02  0.2497E-02 -0.2012E-01  0.2440E-01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.5222E+01  0.1014E+01 -0.8201E+01 -0.2924E+01
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.7351E+00  0.1108E+01 -0.3691E+01  0.1813E+01
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.1614E+01  0.1241E+01 -0.4994E+01  0.1225E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)  -0.6244E+01  0.4822E+00 -0.7652E+01 -0.4982E+01


GROUP NO.  24     TOTAL NO. OF SAMPLES =    2586     28-APR-1988 13:15:23

T1 =    44.0000 SEC.      T2 =    50.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/S, ASTERN, CENTRE ONLY, V/P S.D.TOP AFT


CH DESCRIPTION                      AVERAGE        RMS         MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.1177E+00  0.4430E-03 -0.1207E+00 -0.1159E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)  -0.1178E+02  0.8179E+00 -0.1419E+02 -0.9511E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)  -0.1232E+02  0.8045E+00 -0.1482E+02 -0.1006E+02
 4 CENTRE THRUST (N)              -0.1148E+03  0.9289E+01 -0.1379E+03 -0.9210E+02
 5 CENTRE TORQUE (Nm)             -0.7507E+01  0.4864E+00 -0.8998E+01 -0.6313E+01
 6 SUCT. UPPER BENDING (Nm)        0.2187E+01  0.1871E+01 -0.1855E+01  0.6414E+01
 7 SUCT. LOWER BENDING (Nm)         0.1780E+01  0.117FE+01 -0.3965E+00  0.3902E+01
 8 SUCT. TORSION (Nm)              -0.6169E+00  0.5040E+00 -0.2692E+01  0.5954E+00
 9 TOW FORCE (N)                    0.7148E+02  0.7427E+01  0.5812E+02  0.9137E+02
10 PORT SHAFT SPEED (RPS)          -0.1430E-01  0.1895E-02 -0.4098E-01 -0.7159E-02
11 CENTRE SHAFT SPEED (RPS)        -0.7675E+01  0.2066E-01 -0.7731E+01 -0.7638E+01
12 STRBRD. SHAFT SPEED (RPS)       -0.1444E-02  0.1629E-02 -0.1122E-01  0.1817E-01
13 NOZZLE BN [#1 GAUGE] (Nm)       -0.1589E+01  0.2154E+01 -0.6784E+01  0.3133E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        0.3652E+01  0.2391E+01 -0.2920E+01  0.8824E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        0.2819E+01  0.2614E+01 -0.3207E+01  0.8481E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)    -0.1207E+02  0.7825E+00 -0.1452E+02 -0.9766E+01



GROUP NO.  25     TOTAL NO. OF SAMPLES =     2469     28-APR-1988 13:27:49

T1 =     1.0000 SEC.      T2 =     6.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. BOT. FWD.


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)            -0.1382E+00  0.3921E-03 -0.1392E+00 -0.1372E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     0.5839E+01  0.2581E-01  0.5770E+01  0.5926E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     0.5487E+01  0.2877E-01  0.5386E+01  0.5603E+01
 4 CENTRE THRUST (N)                0.5848E+00  0.1208E+01 -0.1270E+01  0.2788E+01
 5 CENTRE TORQUE (Nm)              -0.7148E-01  0.1038E+00 -0.2364E+00  0.9583E-01
 6 SUCT. UPPER BENDING (Nm)         0.1582E+00  0.4151E-01  0.2503E-01  0.3319E+00
 7 SUCT. LOWER BENDING (Nm)         0.1359E+00  0.4279E-01  0.3768E-01  0.2667E+00
 8 SUCT. TORSION (Nm)               0.2460E-01  0.2627E-01 -0.8632E-01  0.6778E-01
 9 TOW FORCE (N)                   -0.4719E+01  0.9456E+01 -0.2381E+02  0.1118E+02
10 PORT SHAFT SPEED (RPS)          -0.2042E-01  0.6219E-03 -0.2201E-01 -0.1871E-01
11 CENTRE SHAFT SPEED (RPS)         0.2021E-01  0.1362E-02  0.1625E-01  0.2302E-01
12 STRBRD. SHAFT SPEED (RPS)       -0.1306E-02  0.6357E-03 -0.3201E-02  0.2142E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        0.8864E+01  0.1237E+00  0.8552E+01  0.9119E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        0.1602E+02  0.9290E-01  0.1584E+02  0.1626E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        0.1657E+02  0.7838E-01  0.1638E+02  0.1677E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     0.5763E+01  0.2716E-01  0.5699E+01  0.5866E+01



GROUP NO.  25     TOTAL NO. OF SAMPLES =     2469     28-APR-1988 13:27:49

T1 =    13.5000 SEC.      T2 =    19.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. BOT. FWD.


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM
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 1 CARRIAGE SPEED (M/S)              -0.1382E+00  0.4172E-03 -0.1402E+00 -0.1368E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.5819E+01  0.1477E+00  0.4133E+01  0.6342E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.5487E+01  0.1335E+00  0.4354E+01  0.6553E+01
 4 CENTRE THRUST (N)                  0.1241E+02  0.5860E+01  0.3942E+01  0.2208E+02
 5 CENTRE TORQUE (Nm)                -0.2895E+00  0.1220E+00 -0.6481E+00 -0.4950E-01
 6 SUCT. UPPER BENDING (Nm)           0.1589E+00  0.9443E-01 -0.2638E+00  0.7291E+00
 7 SUCT. LOWER BENDING (Nm)          -0.5765E+00  0.1086E+00 -0.1266E+01 -0.8563E-01
 8 SUCT. TORSION (Nm)                 0.2256E-01  0.1405E+00 -0.1139E+01  0.1866E+01
 9 TOW FORCE (N)                      0.1388E+01  0.5241E+01 -0.9686E+01  0.2248E+02
10 PORT SHAFT SPEED (RPS)            -0.2028E-01  0.1355E-02 -0.3273E-01 -0.1128E-01
11 CENTRE SHAFT SPEED (RPS)          -0.7974E-01  0.3584E-02 -0.1024E+00 -0.4814E-01
12 STRBRD. SHAFT SPEED (RPS)         -0.1145E-02  0.2821E-02 -0.3081E-01  0.1906E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          0.9297E+01  0.1733E+00  0.8871E+01  0.1085E+02
14 NOZZLE BN [#2 GAUGE] (Nm)          0.1620E+02  0.9455E-01  0.1580E+02  0.1685E+02
15 NOZZLE BN [#3 GAUGE] (Nm)          0.1671E+02  0.1719E+00  0.1484E+02  0.1709E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.5763E+01  0.1404E+00  0.4503E+01  0.6923E+01



GROUP NO.  25     TOTAL NO. OF SAMPLES =     2469      28-APR-1988 13:27:49

T1 =    21.5000 SEC.      T2 =    27.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. BOT. FWD.


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1395E+00  0.4872E-03 -0.1410E+00 -0.1357E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.6942E+01  0.2136E+01  0.3769E+01  0.1063E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.6536E+01  0.2028E+01  0.3485E+01  0.1011E+02
 4 CENTRE THRUST (N)                  0.3246E+02  0.5712E+01  0.2272E+02  0.4508E+02
 5 CENTRE TORQUE (Nm)                 0.1467E+01  0.1885E+00  0.9125E+00  0.2013E+01
 6 SUCT. UPPER BENDING (Nm)          -0.6929E+00  0.3651E+00 -0.2015E+01  0.3139E+00
 7 SUCT. LOWER BENDING (Nm)          -0.9619E+00  0.2641E+00 -0.1830E+01 -0.2442E+00
 8 SUCT. TORSION (Nm)                 0.7714E+00  0.9128E+00 -0.6257E+00  0.2277E+01
 9 TOW FORCE (N)                     -0.1375E+02  0.4123E+01 -0.2425E+02 -0.2732E+01
10 PORT SHAFT SPEED (RPS)            -0.2093E-01  0.1613E-02 -0.3438E-01 -0.1128E-01
11 CENTRE SHAFT SPEED (RPS)           0.2969E+01  0.7517E-02  0.2900E+01  0.3002E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1207E-02  0.1753E-02 -0.1211E-01  0.1639E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          0.1259E+02  0.7637E+01  0.5828E+00  0.2456E+02
14 NOZZLE BN [#2 GAUGE] (Nm)          0.1910E+02  0.8100E+01  0.6510E+01  0.3182E+02
15 NOZZLE BN [#3 GAUGE] (Nm)          0.1978E+02  0.8817E+01  0.5872E+01  0.3379E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.6822E+01  0.1953E+01  0.3891E+01  0.1007E+02



GROUP NO.  25     TOTAL NO. OF SAMPLES =     2469      28-APR-1988 13:27:49

T1 =    30.0000 SEC.      T2 =    35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. BOT. FWD.
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CH DESCRIPTION                              AVERAGE        RMS         MINIMUM       MAXIMUM


 1 CARRIAGE SPEED (M/S)                  -0.1403E+00   0.5771E-03  -0.1428E+00  -0.1391E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)           0.8005E+01   0.7560E+00   0.6368E+01   0.9928E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)           0.7545E+01   0.7329E+00   0.5576E+01   0.9187E+01
 4 CENTRE THRUST (N)                      0.4926E+02   0.6379E+01   0.3645E+02   0.6342E+02
 5 CENTRE TORQUE (Nm)                     0.2462E+01   0.2315E+00   0.1816E+01   0.3054E+01
 6 SUCT. UPPER BENDING (Nm)              -0.1466E+01   0.5506E+00  -0.2773E+01   0.1875E+00
 7 SUCT. LOWER BENDING (Nm)              -0.1773E+01   0.3659E+00  -0.2728E+01  -0.9840E+00
 8 SUCT. TORSION (Nm)                     0.1389E+01   0.3396E+00   0.6328E+00   0.2277E+01
 9 TOW FORCE (N)                         -0.2613E+02   0.4801E+01  -0.3837E+02  -0.1512E+02
10 PORT SHAFT SPEED (RPS)                -0.2133E-01   0.9817E-03  -0.2943E-01  -0.1871E-01
11 CENTRE SHAFT SPEED (RPS)               0.4065E+01   0.1048E-01   0.4034E+01   0.4112E+01
12 STRBRD. SHAFT SPEED (RPS)             -0.1207E-02   0.1320E-02  -0.1389E-01   0.9266E-02
13 NOZZLE BN [#1 GAUGE] (Nm)              0.1500E+02   0.2698E+01   0.9402E+01   0.2084E+02
14 NOZZLE BN [#2 GAUGE] (Nm)              0.2152E+02   0.2854E+01   0.1538E+02   0.2765E+02
15 NOZZLE BN [#3 GAUGE] (Nm)              0.2226E+02   0.3127E+01   0.1567E+02   0.2893E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)           0.7829E+01   0.7043E+00   0.6338E+01   0.9426E+01



GROUP NO.  25     TOTAL NO. OF SAMPLES =     2469     28-APR-1988 13:27:49

T1 =    41.0000 SEC.      T2 =    46.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD, CENTRE ONLY, V/P, S.D. BOT. FWD.


CH DESCRIPTION                              AVERAGE        RMS         MINIMUM       MAXIMUM


 1 CARRIAGE SPEED (M/S)                  -0.1427E+00   0.7497E-03  -0.1447E+00  -0.1398E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)           0.1467E+02   0.1309E+01   0.1157E+02   0.1811E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)           0.1421E+02   0.1294E+01   0.1106E+02   0.1758E+02
 4 CENTRE THRUST (N)                      0.1127E+03   0.1013E+02   0.8745E+02   0.1375E+03
 5 CENTRE TORQUE (Nm)                     0.6412E+01   0.3882E+00   0.5366E+01   0.7435E+01
 6 SUCT. UPPER BENDING (Nm)              -0.3600E+01   0.8460E+00  -0.5770E+01  -0.1040E+01
 7 SUCT. LOWER BENDING (Nm)              -0.3719E+01   0.5082E+00  -0.4895E+01  -0.2517E+01
 8 SUCT. TORSION (Nm)                     0.2582E+01   0.3697E+00   0.1403E+01   0.3407E+01
 9 TOW FORCE (N)                         -0.7166E+02   0.6367E+01  -0.8379E+02  -0.5858E+02
10 PORT SHAFT SPEED (RPS)                -0.2249E-01   0.8169E-03  -0.2695E-01  -0.1871E-01
11 CENTRE SHAFT SPEED (RPS)               0.6728E+01   0.1420E-01   0.6699E+01   0.6764E+01
12 STRBRD. SHAFT SPEED (RPS)             -0.1065E-02   0.2371E-02  -0.4091E-02   0.3242E-01
13 NOZZLE BN [#1 GAUGE] (Nm)              0.2280E+02   0.4352E+01   0.1089E+02   0.3312E+02
14 NOZZLE BN [#2 GAUGE] (Nm)              0.2903E+02   0.4686E+01   0.1573E+02   0.3974E+02
15 NOZZLE BN [#3 GAUGE] (Nm)              0.3039E+02   0.5156E+01   0.1556E+02   0.4219E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)           0.1447E+02   0.1256E+01   0.1129E+02   0.1771E+02
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GROUP NO.  26     TOTAL NO. OF SAMPLES =    1849      28-APR-1988 13:35:23

T1 =    3.0000 SEC.     T2 =    9.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D BOT. FWD.


CH DESCRIPTION                             AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1593E+00  0.2727E-03 -0.1603E+00 -0.1563E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.6411E+01  0.3911E+00  0.5224E+01  0.7251E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.6052E+01  0.3691E+00  0.5359E+01  0.6988E+01
 4 CENTRE THRUST (N)                     0.1486E+02  0.5253E+01  0.5772E+01  0.2380E+02
 5 CENTRE TORQUE (Nm)                    0.2713E+00  0.1515E+00 -0.1291E+00  0.6703E+00
 6 SUCT. UPPER BENDING (Nm)              0.1772E+01  0.2694E+01 -0.2340E+01  0.5766E+01
 7 SUCT. LOWER BENDING (Nm)              0.1191E+01  0.2221E+01 -0.2023E+01  0.4864E+01
 8 SUCT. TORSION (Nm)                   -0.3437E+00  0.8803E+00 -0.1730E+01  0.1069E+01
 9 TOW FORCE (N)                         0.7378E+01  0.1448E+02 -0.2142E+02  0.3791E+02
10 PORT SHAFT SPEED (RPS)               -0.3991E-01  0.1564E-02 -0.5582E-01 -0.3190E-01
11 CENTRE SHAFT SPEED (RPS)              0.3199E+00  0.3758E-02  0.2941E+00  0.3534E+00
12 STRBRD. SHAFT SPEED (RPS)            -0.1475E-02  0.1382E-02 -0.6763E-02  0.1016E-01
13 NOZZLE BN [#1 GAUGE] (Nm)             0.1052E+02  0.8615E+00  0.8552E+01  0.1241E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.1741E+02  0.9001E+00  0.1563E+02  0.1987E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.1803E+02  0.9705E+00  0.1645E+02  0.1978E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)          0.6364E+01  0.3784E+00  0.4697E+01  0.7089E+01




GROUP NO.  26     TOTAL NO. OF SAMPLES =    1849      28-APR-1988 13:35:23

T1 =   12.5000 SEC.     T2 =   19.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D BOT. FWD.


CH DESCRIPTION                             AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)                 -0.1588E+00  0.2071E-03 -0.1597E+00 -0.1581E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)          0.7943E+01  0.6353E+00  0.6497E+01  0.9642E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)          0.7474E+01  0.5906E+00  0.6146E+01  0.9160E+01
 4 CENTRE THRUST (N)                     0.4073E+02  0.5969E+01  0.2933E+02  0.5395E+02
 5 CENTRE TORQUE (Nm)                    0.1839E+01  0.2094E+00  0.1182E+01  0.2324E+01
 6 SUCT. UPPER BENDING (Nm)              0.5067E+00  0.2525E+01 -0.3676E+01  0.4665E+01
 7 SUCT. LOWER BENDING (Nm)              0.1976E+00  0.2062E+01 -0.3115E+01  0.3473E+01
 8 SUCT. TORSION (Nm)                    0.7373E+00  0.8660E+00 -0.8312E+00  0.2431E+01
 9 TOW FORCE (N)                        -0.6501E+01  0.1061E+02 -0.2685E+02  0.1226E+02
10 PORT SHAFT SPEED (RPS)               -0.3973E-01  0.1434E-02 -0.5170E-01 -0.2695E-01
11 CENTRE SHAFT SPEED (RPS)              0.3455E+01  0.9048E-02  0.3420E+01  0.3507E+01
12 STRBRD. SHAFT SPEED (RPS)            -0.1797E-02  0.1400E-02 -0.1923E-01  0.8375E-02
13 NOZZLE BN [#1 GAUGE] (Nm)             0.1514E+02  0.3479E+01  0.7950E+01  0.2261E+02
14 NOZZLE BN [#2 GAUGE] (Nm)             0.2218E+02  0.3696E+01  0.1433E+02  0.3000E+02
15 NOZZLE BN [#3 GAUGE] (Nm)             0.2306E+02  0.4115E+01  0.1441E+02  0.3168E+02
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16 NOZZLE TORSION [ #1 Gg] (Nm)    0.7785E+01  0.5520E+00  0.6561E+01  0.9342E+01


GROUP NO.  26     TOTAL NO. OF SAMPLES =     1849     28-APR-1988 13:35:23

T1 =    21.5000 SEC.      T2 =    26.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D BOT. FWD.


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1576E+00  0.4921E-03 -0.1585E+00 -0.1565E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.1104E+02  0.5470E+00  0.9356E+01  0.1273E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.1051E+02  0.5332E+00  0.9024E+01  0.1220E+02
 4 CENTRE THRUST (N)                 0.7792E+02  0.7945E+01  0.6120E+02  0.9291E+02
 5 CENTRE TORQUE (Nm)                0.4156E+01  0.3248E+00  0.3158E+01  0.4978E+01
 6 SUCT. UPPER BENDING (Nm)         -0.1058E+01  0.2656E+01 -0.6420E+01  0.4159E+01
 7 SUCT. LOWER BENDING (Nm)         -0.1406E+01  0.2174E+01 -0.5881E+01  0.2944E+01
 8 SUCT. TORSION (Nm)                0.1694E+01  0.8281E+00 -0.8632E-01  0.3587E+01
 9 TOW FORCE (N)                    -0.3090E+02  0.9998E+01 -0.4793E+02 -0.1077E+02
10 PORT SHAFT SPEED (RPS)           -0.3926E-01  0.1176E-02 -0.4592E-01 -0.2943E-01
11 CENTRE SHAFT SPEED (RPS)          0.5406E+01  0.1370E-01  0.5369E+01  0.5439E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1712E-02  0.1076E-02 -0.8544E-02  0.4813E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.2039E+02  0.1570E+01  0.1680E+02  0.2449E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.2751E+02  0.1610E+01  0.2344E+02  0.3224E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2878E+02  0.1748E+01  0.2435E+02  0.3389E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.1082E+02  0.5305E+00  0.9370E+01  0.1262E+02


GROUP NO.  26     TOTAL NO. OF SAMPLES =     1849     28-APR-1988 13:35:23

T1 =    28.0000 SEC.      T2 =    30.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=2.0 KTS, Vm=0.266 M/S, AHEAD, CENTRE ONLY, V/P, S.D BOT. FWD.


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1568E+00  0.3093E-03 -0.1573E+00 -0.1559E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      0.2109E+02  0.1493E+01  0.1707E+02  0.2446E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)      0.2051E+02  0.1482E+01  0.1717E+02  0.2393E+02
 4 CENTRE THRUST (N)                 0.1637E+03  0.1597E+02  0.1353E+03  0.2103E+03
 5 CENTRE TORQUE (Nm)                0.9248E+01  0.6404E+00  0.7937E+01  0.1087E+02
 6 SUCT. UPPER BENDING (Nm)         -0.4677E+01  0.7413E+01 -0.1734E+02  0.7481E+01
 7 SUCT. LOWER BENDING (Nm)         -0.4382E+01  0.1026E+01 -0.6462E+01 -0.2217E+01
 8 SUCT. TORSION (Nm)                0.3428E+01  0.4528E+00  0.2071E+01  0.4537E+01
 9 TOW FORCE (N)                    -0.7431E+02  0.2685E+02 -0.1131E+03 -0.3250E+02
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10 PORT SHAFT SPEED (RPS)           -0.3897E-01  0.1134E-02 -0.4180E-01 -0.3025E-01
11 CENTRE SHAFT SPEED (RPS)          0.8113E+01  0.2207E-01  0.8060E+01  0.8158E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1737E-02  0.1376E-02 -0.7653E-02  0.7485E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         0.3414E+02  0.3271E+01  0.2424E+02  0.4266E+02
14 NOZZLE BN [#2 GAUGE] (Nm)         0.4117E+02  0.3390E+01  0.3084E+02  0.4991E+02
15 NOZZLE BN [#3 GAUGE] (Nm)         0.4382E+02  0.3774E+01  0.3246E+02  0.5384E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)      0.2058E+02  0.1463E+01  0.1746E+02  0.2394E+02


GROUP NO.  27     TOTAL NO. OF SAMPLES =    1522     28-APR-1988 13:44:24

T1 =    1.0000 SEC.     T2 =    5.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. BOT. AFT.


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1665E+00  0.2355E-03 -0.1671E+00 -0.1651E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.8577E+00  0.1346E+00 -0.1949E+01  0.4163E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.9661E+00  0.1446E+00 -0.2135E+01 -0.4790E+00
 4 CENTRE THRUST (N)                 0.1634E+02  0.5829E+01  0.6210E+01  0.2535E+02
 5 CENTRE TORQUE (Nm)               -0.1144E+00  0.1441E+00 -0.4994E+00  0.1996E+00
 6 SUCT. UPPER BENDING (Nm)         -0.1017E+00  0.7260E-01 -0.4273E+00  0.4573E+00
 7 SUCT. LOWER BENDING (Nm)         -0.3780E+00  0.7903E-01 -0.8550E+00  0.8184E-02
 8 SUCT. TORSION (Nm)               -0.2797E-01  0.1271E+00 -0.4192E+00  0.1430E+01
 9 TOW FORCE (N)                    -0.4909E+01  0.3291E+01 -0.1164E+02  0.3102E+00
10 PORT SHAFT SPEED (RPS)           -0.4393E-01  0.2365E-02 -0.6654E-01 -0.3850E-01
11 CENTRE SHAFT SPEED (RPS)         -0.8905E+00  0.6146E-02 -0.9496E+00 -0.8615E+00
12 STRBRD. SHAFT SPEED (RPS)        -0.1890E-02  0.1745E-02 -0.1389E-01  0.6594E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.5706E+01  0.1775E+00 -0.6395E+01 -0.3774E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.6233E+00  0.2001E+00 -0.1377E+01  0.1848E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2534E-01  0.1385E+00 -0.3116E+00  0.1011E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.6594E+00  0.1051E+00 -0.1561E+01  0.3306E+00


GROUP NO.  27     TOTAL NO. OF SAMPLES =    1522     28-APR-1988 13:44:24

T1 =    8.0000 SEC.     T2 =   14.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. BOT. AFT.


CH DESCRIPTION                         AVERAGE        RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1674E+00  0.3873E-03 -0.1685E+00 -0.1625E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.5142E+01  0.2352E+00 -0.6159E+01 -0.4573E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.5447E+01  0.2271E+00 -0.6100E+01 -0.4796E+01
 4 CENTRE THRUST (N)                -0.1526E+02  0.6654E+01 -0.2769E+02 -0.7131E+00
 5 CENTRE TORQUE (Nm)               -0.1846E+01  0.2584E+00 -0.2548E+01 -0.1202E+01
 6 SUCT. UPPER BENDING (Nm)         -0.7700E+00  0.3939E+00 -0.2016E+01  0.4754E+00
 7 SUCT. LOWER BENDING (Nm)         -0.1129E+01  0.3247E+00 -0.2070E+01  0.8184E-02
 8 SUCT. TORSION (Nm)               -0.6775E+00  0.1339E+00 -0.1010E+01 -0.2395E+00
 9 TOW FORCE (N)                     0.1747E+02  0.1252E+02 -0.4253E+01  0.4008E+02
10 PORT SHAFT SPEED (RPS)           -0.4390E-01  0.8406E-03 -0.5005E-01 -0.3850E-01
11 CENTRE SHAFT SPEED (RPS)         -0.3829E+01  0.1046E-01 -0.3859E+01 -0.3800E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1893E-02  0.1058E-02 -0.8544E-02  0.8375E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.4064E+01  0.4076E+00 -0.4978E+01 -0.2534E+01
14 NOZZLE BN [#2 GAUGE] (Nm)         0.2489E+01  0.4606E+00  0.5507E+00  0.4722E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.1640E+01  0.4768E+00 -0.4903E+00  0.3084E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.5164E+01  0.2473E+00 -0.5816E+01 -0.3591E+01


GROUP NO.  27     TOTAL NO. OF SAMPLES =     1522     28-APR-1988 13:44:24

T1 =   16.0000 SEC.     T2 =   21.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. BOT. AFT.


CH DESCRIPTION                         AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1684E+00  0.3205E-03 -0.1715E+00 -0.1680E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.9251E+01  0.1015E+01 -0.1138E+02 -0.7224E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.9723E+01  0.1035E+01 -0.1188E+02 -0.7674E+01
 4 CENTRE THRUST (N)                -0.4264E+02  0.7578E+01 -0.5928E+02 -0.2482E+02
 5 CENTRE TORQUE (Nm)               -0.3362E+01  0.3549E+00 -0.4202E+01 -0.2351E+01
 6 SUCT. UPPER BENDING (Nm)         -0.5498E+00  0.1346E+01 -0.3641E+01  0.1884E+01
 7 SUCT. LOWER BENDING (Nm)         -0.1262E+01  0.1048E+01 -0.3603E+01  0.4662E+00
 8 SUCT. TORSION (Nm)               -0.1237E+01  0.5065E+00 -0.2243E+01 -0.5966E-01
 9 TOW FORCE (N)                     0.3709E+02  0.1198E+02  0.1487E+02  0.5507E+02
10 PORT SHAFT SPEED (RPS)           -0.4419E-01  0.5362E-03 -0.4592E-01 -0.4262E-01
11 CENTRE SHAFT SPEED (RPS)         -0.5170E+01  0.1936E-01 -0.5211E+01 -0.5137E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1792E-02  0.1480E-02 -0.5872E-02  0.1105E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.3204E+01  0.1829E+01 -0.8343E+01  0.7244E+00
14 NOZZLE BN [#2 GAUGE] (Nm)         0.3480E+01  0.2005E+01 -0.2219E+01  0.7772E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         0.2429E+01  0.2220E+01 -0.3886E+01  0.7266E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.9419E+01  0.1008E+01 -0.1152E+02 -0.7402E+01


GROUP NO.  27     TOTAL NO. OF SAMPLES =     1522     28-APR-1988 13:44:24

T1 =   24.0000 SEC.     T2 =   29.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, ASTERN, CENTRE ONLY, V/P, S.D. BOT. AFT.
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CH DESCRIPTION                        AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1691E+00  0.2835E-03 -0.1704E+00 -0.1685E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.2000E+02  0.8209E+00 -0.2193E+02 -0.1692E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.2085E+02  0.8156E+00 -0.2272E+02 -0.1780E+02
 4 CENTRE THRUST (N)                -0.1064E+03  0.9862E+01 -0.1257E+03 -0.7961E+02
 5 CENTRE TORQUE (Nm)               -0.6913E+01  0.4741E+00 -0.7981E+01 -0.5572E+01
 6 SUCT. UPPER BENDING (Nm)          0.3294E+01  0.6334E+00  0.1703E+01  0.4754E+01
 7 SUCT. LOWER BENDING (Nm)          0.1517E+01  0.3969E+00  0.5895E+00  0.2421E+01
 8 SUCT. TORSION (Nm)               -0.2622E+01  0.2292E+00 -0.3167E+01 -0.1883E+01
 9 TOW FORCE (N)                     0.7805E+02  0.1148E+02  0.5920E+02  0.1003E+03
10 PORT SHAFT SPEED (RPS)           -0.4426E-01  0.1394E-02 -0.5170E-01 -0.3108E-01
11 CENTRE SHAFT SPEED (RPS)         -0.7349E+01  0.2341E-01 -0.7402E+01 -0.7292E+01
12 STRBRD. SHAFT SPEED (RPS)        -0.1913E-02  0.2932E-02 -0.2546E-01  0.3509E-01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.5379E+01  0.1713E+01 -0.1086E+02 -0.9402E+00
14 NOZZLE BN [#2 GAUGE] (Nm)         0.1459E+01  0.1879E+01 -0.3095E+01  0.6300E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.3092E+00  0.2074E+01 -0.5208E+01  0.5121E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.2040E+02  0.8284E+00 -0.2292E+02 -0.1744E+02



GROUP NO.  28     TOTAL NO. OF SAMPLES =     2003     28-APR-1988 13:48:27

T1 =    4.5000 SEC.     T2 =   11.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/D, CENTRE ONLY, V/P , S.D. BOT. AFT.


CH DESCRIPTION                        AVERAGE       RMS        MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.1835E+00  0.4160E-03 -0.1847E+00 -0.1804E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1360E+01  0.2301E+00 -0.3300E+01 -0.7746E-01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1413E+01  0.1805E+00 -0.1837E+01 -0.1076E+01
 4 CENTRE THRUST (N)                 0.1682E+02  0.5713E+01  0.6409E+01  0.2578E+02
 5 CENTRE TORQUE (Nm)               -0.5156E-01  0.1429E+00 -0.3679E+00  0.3934E+00
 6 SUCT. UPPER BENDING (Nm)         -0.1706E+01  0.8702E+00 -0.3334E+01  0.3310E+00
 7 SUCT. LOWER BENDING (Nm)         -0.1785E+01  0.7407E+00 -0.3251E+01 -0.9751E-01
 8 SUCT. TORSION (Nm)                0.1962E+00  0.2794E+00 -0.1549E+01  0.2098E+01
 9 TOW FORCE (N)                    -0.1340E+02  0.1514E+02 -0.4163E+02  0.1617E+02
10 PORT SHAFT SPEED (RPS)           -0.4519E-01  0.2148E-02 -0.6489E-01 -0.2366E-01
11 CENTRE SHAFT SPEED (RPS)         -0.8280E+00  0.3943E-02 -0.8428E+00 -0.7988E+00
12 STRBRD. SHAFT SPEED (RPS)        -0.1873E-02  0.1363E-02 -0.1478E-01  0.6594E-02
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.6671E+01  0.2637E+00 -0.8838E+01 -0.5651E+01
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.8042E-01  0.2605E+00 -0.9217E+00  0.1392E+01
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.9256E+00  0.2820E+00 -0.2099E+01  0.1173E+00
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1097E+01  0.1954E+00 -0.1644E+01  0.1081E+00



GROUP NO.  28     TOTAL NO. OF SAMPLES =     2003     28-APR-1988 13:48:27

T1 =   14.0000 SEC.     T2 =   20.0000 SEC.
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PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/D, CENTRE ONLY, V/P , S.D. BOT. AFT.


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1837E+00  0.2128E-03 -0.1845E+00 -0.1830E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.5109E+01  0.2933E+00 -0.6107E+01 -0.3664E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.5351E+01  0.2860E+00 -0.6317E+01 -0.4416E+01
 4 CENTRE THRUST (N)                 -0.1254E+02  0.6450E+01 -0.2534E+02  0.1475E+01
 5 CENTRE TORQUE (Nm)                -0.1754E+01  0.2697E+00 -0.2413E+01 -0.1081E+01
 6 SUCT. UPPER BENDING (Nm)          -0.2256E+01  0.6857E+00 -0.3948E+01 -0.5356E+00
 7 SUCT. LOWER BENDING (Nm)          -0.2396E+01  0.5723E+00 -0.3779E+01 -0.9783E+00
 8 SUCT. TORSION (Nm)                -0.4615E+00  0.2236E+00 -0.1729E+01  0.1199E+01
 9 TOW FORCE (N)                      0.2735E+01  0.9867E+01 -0.1621E+02  0.2030E+02
10 PORT SHAFT SPEED (RPS)            -0.4508E-01  0.1044E-02 -0.5417E-01 -0.3603E-01
11 CENTRE SHAFT SPEED (RPS)          -0.3905E+01  0.1095E-01 -0.3932E+01 -0.3878E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.2059E-02  0.1194E-02 -0.1656E-01  0.3610E-03
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.5557E+01  0.5520E+00 -0.8201E+01 -0.4163E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          0.1046E+01  0.5656E+00 -0.7814E+00  0.2829E+01
15 NOZZLE BN [#3 GAUGE] (Nm)         -0.2047E-01  0.6107E+00 -0.2063E+01  0.1726E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.5033E+01  0.2695E+00 -0.5983E+01 -0.4120E+01



GROUP NO.  28     TOTAL NO. OF SAMPLES =     2003     28-APR-1988 13:48:27

T1 =    22.5000 SEC.      T2 =    29.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/D, CENTRE ONLY, V/P , S.D. BOT. AFT.


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)              -0.1842E+00  0.1994E-03 -0.1868E+00 -0.1837E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)      -0.9421E+01  0.8444E+00 -0.1136E+02 -0.7848E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)      -0.9823E+01  0.8720E+00 -0.1177E+02 -0.6724E+01
 4 CENTRE THRUST (N)                 -0.4230E+02  0.7800E+01 -0.5689E+02 -0.2466E+02
 5 CENTRE TORQUE (Nm)                -0.3486E+01  0.3719E+00 -0.4448E+01 -0.2544E+01
 6 SUCT. UPPER BENDING (Nm)          -0.1941E+01  0.9545E+00 -0.4183E+01  0.9626E-01
 7 SUCT. LOWER BENDING (Nm)          -0.2372E+01  0.5888E+00 -0.3920E+01 -0.1436E+01
 8 SUCT. TORSION (Nm)                -0.1017E+01  0.3403E+00 -0.1935E+01  0.9444E-01
 9 TOW FORCE (N)                      0.1806E+02  0.9756E+01 -0.3418E+00  0.3638E+02
10 PORT SHAFT SPEED (RPS)            -0.4506E-01  0.2156E-02 -0.5087E-01 -0.1788E-01
11 CENTRE SHAFT SPEED (RPS)          -0.5412E+01  0.2025E-01 -0.5450E+01 -0.5377E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1923E-02  0.8343E-03 -0.7653E-02  0.3923E-02
13 NOZZLE BN [#1 GAUGE] (Nm)         -0.4531E+01  0.1545E+01 -0.7953E+01 -0.1826E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2042E+01  0.1694E+01 -0.1763E+01  0.5073E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          0.7921E+00  0.1909E+01 -0.3528E+01  0.4799E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)      -0.9495E+01  0.8419E+00 -0.1132E+02 -0.6873E+01
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GROUP NO.  28     TOTAL NO. OF SAMPLES =     2003     28-APR-1988 13:48:27

T1 =    35.0000 SEC.     T2 =   39.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=-2.0 KTS, Vm=-0.266 M/D, CENTRE ONLY, V/P , S.D. BOT. AFT.


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1847E+00  0.3819E-03 -0.1877E+00 -0.1815E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)       -0.2228E+02  0.1055E+01 -0.2516E+02 -0.1952E+02
 3 NOZZLE TORSION [ #3 Gg] (Nm)       -0.2310E+02  0.1057E+01 -0.2595E+02 -0.2033E+02
 4 CENTRE THRUST (N)                  -0.1157E+03  0.8693E+01 -0.1336E+03 -0.8920E+02
 5 CENTRE TORQUE (Nm)                 -0.7667E+01  0.5192E+00 -0.8666E+01 -0.6199E+01
 6 SUCT. UPPER BENDING (Nm)            0.2751E+01  0.1323E+01 -0.2829E+00  0.5964E+01
 7 SUCT. LOWER BENDING (Nm)            0.1118E+01  0.8599E+00 -0.9254E+00  0.2827E+01
 8 SUCT. TORSION (Nm)                 -0.2718E+01  0.4004E+00 -0.3578E+01 -0.1729E+01
 9 TOW FORCE (N)                       0.5964E+02  0.1387E+02  0.3204E+02  0.8463E+02
10 PORT SHAFT SPEED (RPS)             -0.4551E-01  0.8555E-03 -0.5335E-01 -0.4427E-01
11 CENTRE SHAFT SPEED (RPS)           -0.7881E+01  0.4286E-01 -0.7995E+01 -0.7772E+01
12 STRBRD. SHAFT SPEED (RPS)          -0.2669E-02  0.3575E-02 -0.2546E-01  0.2084E-01
13 NOZZLE BN [#1 GAUGE] (Nm)          -0.7910E+01  0.2067E+01 -0.1252E+02 -0.3349E+01
14 NOZZLE BN [#2 GAUGE] (Nm)          -0.1477E+01  0.2333E+01 -0.7898E+01  0.3706E+01
15 NOZZLE BN [#3 GAUGE] (Nm)          -0.3782E+01  0.2539E+01 -0.9891E+01  0.2012E+01
16 NOZZLE TORSION [ #1 Gg] (Nm)       -0.2258E+02  0.1020E+01 -0.2523E+02 -0.2003E+02



GROUP NO.  31     TOTAL NO. OF SAMPLES =      587     28-APR-1988 15:08:54

T1 =     1.0000 SEC.     T2 =   10.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=+5.0 KTS, Vm=0.664 M/S, AHEAD DRAG FORCES


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)               -0.1917E+00  0.2838E-03 -0.1922E+00 -0.1910E+00
 2 NOZZLE TORSION [ #2 Gg] (Nm)        0.3473E-01  0.2911E-01 -0.3228E-01  0.1236E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)        0.1464E-01  0.3111E-01 -0.7711E-01  0.1401E+00
 4 CENTRE THRUST (N)                   0.7583E+01  0.9641E+00  0.5693E+01  0.9472E+01
 5 CENTRE TORQUE (Nm)                 -0.2094E+00  0.2363E+00 -0.5928E+00  0.1783E+00
 6 SUCT. UPPER BENDING (Nm)            0.2667E+02  0.8076E+00  0.2471E+02  0.2933E+02
 7 SUCT. LOWER BENDING (Nm)            0.2203E+02  0.6161E+00  0.2034E+02  0.2381E+02
 8 SUCT. TORSION (Nm)                 -0.8431E+01  0.8647E+00 -0.1010E+02 -0.6449E+01
 9 TOW FORCE (N)                       0.6158E+02  0.1121E+02  0.2971E+02  0.8513E+02
10 PORT SHAFT SPEED (RPS)             -0.4900E-01  0.5225E-03 -0.5087E-01 -0.4592E-01
11 CENTRE SHAFT SPEED (RPS)            0.1717E-01  0.1911E-02  0.9468E-02  0.2133E-01
12 STRBRD. SHAFT SPEED (RPS)          -0.2445E-02  0.5559E-03 -0.4982E-02  0.3610E-03
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GROUP NO.  38     TOTAL NO. OF SAMPLES =    4557    28-APR-1988 16:05:03

T1 =   23.5000 SEC.      T2 =   35.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD BOLLARD, CENT. SHAFT 100% POWER, WING SHAFTS VARIABLE


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.3131E-03  0.1659E-02 -0.1842E-01  0.1544E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.9063E+00  0.6304E+00 -0.2436E+01  0.6824E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.1462E+00  0.6690E+00 -0.2165E+01  0.1908E+01
 4 CENTRE THRUST (N)                 0.9341E+02  0.5245E+01  0.8069E+02  0.1063E+03
 5 CENTRE TORQUE (Nm)                0.5242E+01  0.3301E+00  0.4452E+01  0.6051E+01
 6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)               -0.4134E+03  0.1727E-04 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                    -0.2030E+03  0.5872E+01 -0.2177E+03 -0.1864E+03
10 PORT SHAFT SPEED (RPS)            0.4660E+01  0.2677E-02  0.4643E+01  0.4697E+01
11 CENTRE SHAFT SPEED (RPS)          0.6991E+01  0.1627E-01  0.6940E+01  0.7042E+01
12 STRBRD. SHAFT SPEED (RPS)         0.3571E+01  0.3779E-02  0.3546E+01  0.3597E+01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.1537E+02  0.8950E+00 -0.1770E+02 -0.1171E+02
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.2201E+02  0.9612E+00 -0.2572E+02 -0.1969E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2433E+02  0.9619E+00 -0.2689E+02 -0.2192E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.1386E+00  0.6603E+00 -0.2776E+01  0.2759E+01
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GROUP NO.  38     TOTAL NO. OF SAMPLES =    4557     28-APR-1988 16:05:03

T1 =   42.0000 SEC.      T2 =   55.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD BOLLARD, CENT. SHAFT 100% POWER, WING SHAFTS VARIABLE


CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.2150E-03  0.2831E-02 -0.2020E-01  0.2925E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1147E+01  0.7234E+00 -0.3398E+01  0.1254E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.3752E+00  0.7335E+00 -0.2518E+01  0.1311E+01
 4 CENTRE THRUST (N)                 0.9323E+02  0.5233E+01  0.7958E+02  0.1060E+03
 5 CENTRE TORQUE (Nm)                0.5317E+01  0.3515E+00  0.4013E+01  0.6086E+01
 6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)               -0.4134E+03  0.1926E-04 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                    -0.2466E+03  0.6389E+01 -0.2603E+03 -0.2292E+03
10 PORT SHAFT SPEED (RPS)            0.6043E+01  0.4351E-02  0.6005E+01  0.6073E+01
11 CENTRE SHAFT SPEED (RPS)          0.6991E+01  0.1566E-01  0.6955E+01  0.7031E+01
12 STRBRD. SHAFT SPEED (RPS)         0.4267E+01  0.5280E-02  0.4240E+01  0.4315E+01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.1589E+02  0.1072E+01 -0.1880E+02 -0.1221E+02
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.2248E+02  0.1129E+01 -0.2551E+02 -0.1983E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2482E+02  0.1182E+01 -0.2796E+02 -0.2160E+02
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16 NOZZLE TORSION [ #1 Gg] (Nm)  -0.3773E+00  0.7285E+00 -0.2025E+01  0.2843E+01


GROUP NO.  38     TOTAL NO. OF SAMPLES =     4557     28-APR-1988 16:05:03

T1 =   64.0000 SEC.      T2 =   74.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD BOLLARD, CENT. SHAFT 100% POWER, WING SHAFTS VARIABLE


CH DESCRIPTION                       AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.2216E-03  0.2900E-02 -0.1218E-01  0.3772E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1126E+01  0.8192E+00 -0.3216E+01  0.8643E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.3099E+00  0.8752E+00 -0.2327E+01  0.2098E+01
 4 CENTRE THRUST (N)                 0.9447E+02  0.5781E+01  0.7842E+02  0.1104E+03
 5 CENTRE TORQUE (Nm)                0.5416E+01  0.3475E+00  0.4560E+01  0.6456E+01
 6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)               -0.4134E+03  0.1427E-04 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                    -0.3503E+03  0.4397E+01 -0.3642E+03 -0.3385E+03
10 PORT SHAFT SPEED (RPS)            0.7324E+01  0.4646E-02  0.7301E+01  0.7344E+01
11 CENTRE SHAFT SPEED (RPS)          0.6990E+01  0.1645E-01  0.6948E+01  0.7031E+01
12 STRBRD. SHAFT SPEED (RPS)         0.7549E+01  0.1193E-01  0.7513E+01  0.7586E+01
13 NOZZLE BN [#1 GAUGE] (Nm)        -0.1639E+02  0.1351E+01 -0.2029E+02 -0.1218E+02
14 NOZZLE BN [#2 GAUGE] (Nm)        -0.2312E+02  0.1463E+01 -0.2741E+02 -0.1885E+02
15 NOZZLE BN [#3 GAUGE] (Nm)        -0.2552E+02  0.1563E+01 -0.3096E+02 -0.2049E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)     -0.3702E+00  0.8430E+00 -0.2943E+01  0.1702E+01


GROUP NO.  38     TOTAL NO. OF SAMPLES =     4557     28-APR-1988 16:05:03

T1 =   79.0000 SEC.      T2 =   88.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=0, AHEAD BOLLARD, CENT. SHAFT 100% POWER, WING SHAFTS VARIABLE


CH DESCRIPTION                       AVERAGE       RMS        MINIMUM      MAXIMUM


 1 CARRIAGE SPEED (M/S)             -0.2996E-03  0.2548E-02 -0.2466E-01  0.2480E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)     -0.1417E+01  0.9338E+00 -0.4047E+01  0.7863E+00
 3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.5846E+00  0.9526E+00 -0.3061E+01  0.1881E+01
 4 CENTRE THRUST (N)                 0.9558E+02  0.6669E+01  0.7771E+02  0.1185E+03
 5 CENTRE TORQUE (Nm)                0.5469E+01  0.3659E+00  0.4511E+01  0.6421E+01
 6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)               -0.4134E+03  0.1096E-04 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                    -0.4278E+03  0.5214E+01 -0.4452E+03 -0.4203E+03
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10 PORT SHAFT SPEED (RPS)          0.8837E+01  0.3556E-02  0.8817E+01  0.8862E+01
11 CENTRE SHAFT SPEED (RPS)        0.6989E+01  0.1652E-01  0.6935E+01  0.7062E+01
12 STRBRD. SHAFT SPEED (RPS)       0.8793E+01  0.9446E-02  0.8756E+01  0.8818E+01
13 NOZZLE BN [#1 GAUGE] (Nm)      -0.1647E+02  0.1406E+01 -0.2043E+02 -0.1295E+02
14 NOZZLE BN [#2 GAUGE] (Nm)      -0.2342E+02  0.1542E+01 -0.2765E+02 -0.1966E+02
15 NOZZLE BN [#3 GAUGE] (Nm)      -0.2579E+02  0.1660E+01 -0.3035E+02 -0.2106E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)   -0.6324E+00  0.9198E+00 -0.2998E+01  0.1758E+01


GROUP NO.  39     TOTAL NO. OF SAMPLES =     2876     28-APR-1988 16:15:30

T1 =    0.5000 SEC.     T2 =    6.5000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=o, ASTERN BOLLARD W/ CENT. @ 100% PWR, WINGS VARIABLE


CH DESCRIPTION                       AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.2358E-03  0.2491E-02 -0.2555E-01  0.1722E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.8966E+00  0.7865E+00 -0.5650E+00  0.2138E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)    0.9566E-02  0.8451E+00 -0.1513E+01  0.1420E+01
 4 CENTRE THRUST (N)              -0.9777E+02  0.6597E+01 -0.1101E+03 -0.8307E+02
 5 CENTRE TORQUE (Nm)             -0.8447E+01  0.6458E+00 -0.9991E+01 -0.7309E+01
 6 SUCT. UPPER BENDING (Nm)        0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)        0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)             -0.4134E+03  0.0000E+00 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                   0.1874E+03  0.4036E+01  0.1798E+03  0.1958E+03
10 PORT SHAFT SPEED (RPS)         -0.2282E+00  0.5923E-02 -0.2430E+00 -0.2018E+00
11 CENTRE SHAFT SPEED (RPS)       -0.8621E+01  0.2825E-01 -0.8685E+01 -0.8570E+01
12 STRBRD. SHAFT SPEED (RPS)      -0.3015E+00  0.1409E-02 -0.3149E+00 -0.2935E+00
13 NOZZLE BN [#1 GAUGE] (Nm)       0.3017E+02  0.1285E+01  0.2682E+02  0.3309E+02
14 NOZZLE BN [#2 GAUGE] (Nm)       0.2557E+02  0.1342E+01  0.2202E+02  0.2844E+02
15 NOZZLE BN [#3 GAUGE] (Nm)       0.2824E+02  0.1351E+01  0.2458E+02  0.3159E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)    0.2348E+00  0.8587E+00 -0.1747E+01  0.1591E+01


GROUP NO.  39     TOTAL NO. OF SAMPLES =     2876     28-APR-1988 16:15:30

T1 =   17.0000 SEC.     T2 =   28.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=o, ASTERN BOLLARD W/ CENT. @ 100% PWR, WINGS VARIABLE


CH DESCRIPTION                       AVERAGE       RMS       MINIMUM     MAXIMUM


 1 CARRIAGE SPEED (M/S)           -0.3527E-03  0.2547E-02 -0.3045E-01  0.2391E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)    0.8366E+00  0.7895E+00 -0.9029E+00  0.2580E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)   -0.3584E-01  0.8779E+00 -0.4391E+01  0.2071E+01
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  4 CENTRE THRUST (N)                -0.9712E+02  0.6660E+01 -0.1134E+03 -0.8156E+02
  5 CENTRE TORQUE (Nm)               -0.8452E+01  0.6452E+00 -0.1015E+02 -0.7206E+01
  6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
  7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
  8 SUCT. TORSION (Nm)               -0.4134E+03  0.1641E-04 -0.4134E+03 -0.4134E+03
  9 TOW FORCE (N)                     0.2334E+03  0.4902E+01  0.2252E+03  0.2445E+03
 10 PORT SHAFT SPEED (RPS)           -0.4448E+01  0.4416E-02 -0.4469E+01 -0.4425E+01
 11 CENTRE SHAFT SPEED (RPS)         -0.8602E+01  0.2945E-01 -0.8680E+01 -0.8539E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.4723E+01  0.5446E-02 -0.4749E+01 -0.4707E+01
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.2987E+02  0.1273E+01  0.2686E+02  0.3373E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.2500E+02  0.1321E+01  0.2192E+02  0.3124E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.2763E+02  0.1335E+01  0.2451E+02  0.3094E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.2206E+00  0.8518E+00 -0.2136E+01  0.1869E+01



GROUP NO.  39     TOTAL NO. OF SAMPLES =     2876     28-APR-1988 16:15:30

T1 =   36.5000 SEC.     T2 =   43.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=o, ASTERN BOLLARD W/ CENT. @ 100% PWR, WINGS VARIABLE


CH DESCRIPTION                        AVERAGE        RMS        MINIMUM     MAXIMUM


  1 CARRIAGE SPEED (M/S)              0.7147E-05  0.3025E-02 -0.1753E-01  0.3416E-01
  2 NOZZLE TORSION [ #2 Gg] (Nm)      0.8555E+00  0.8012E+00 -0.8769E+00  0.2995E+01
  3 NOZZLE TORSION [ #3 Gg] (Nm)     -0.3514E-01  0.8493E+00 -0.1947E+01  0.2153E+01
  4 CENTRE THRUST (N)                -0.9671E+02  0.6174E+01 -0.1092E+03 -0.8104E+02
  5 CENTRE TORQUE (Nm)               -0.8461E+01  0.6308E+00 -0.9991E+01 -0.7372E+01
  6 SUCT. UPPER BENDING (Nm)          0.2915E+03  0.0000E+00  0.2915E+03  0.2915E+03
  7 SUCT. LOWER BENDING (Nm)          0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
  8 SUCT. TORSION (Nm)               -0.4134E+03  0.0000E+00 -0.4134E+03 -0.4134E+03
  9 TOW FORCE (N)                     0.3012E+03  0.3454E+01  0.2919E+03  0.3138E+03
 10 PORT SHAFT SPEED (RPS)           -0.7083E+01  0.4829E-02 -0.7100E+01 -0.7057E+01
 11 CENTRE SHAFT SPEED (RPS)         -0.8589E+01  0.2959E-01 -0.8671E+01 -0.8527E+01
 12 STRBRD. SHAFT SPEED (RPS)        -0.7764E+01  0.6684E-02 -0.7793E+01 -0.7740E+01
 13 NOZZLE BN [#1 GAUGE] (Nm)         0.2968E+02  0.1297E+01  0.2668E+02  0.3312E+02
 14 NOZZLE BN [#2 GAUGE] (Nm)         0.2457E+02  0.1334E+01  0.2041E+02  0.2739E+02
 15 NOZZLE BN [#3 GAUGE] (Nm)         0.2718E+02  0.1371E+01  0.2247E+02  0.3069E+02
 16 NOZZLE TORSION [ #1 Gg] (Nm)      0.2505E+00  0.9044E+00 -0.2998E+01  0.3121E+01



GROUP NO.  39     TOTAL NO. OF SAMPLES =     2876     28-APR-1988 16:15:30

T1 =   47.0000 SEC.     T2 =   53.0000 SEC.

PROJ. # R4034 BOLLARD/SELF PROPULSION SUCTION TESTS
Vs=o, ASTERN BOLLARD W/ CENT. @ 100% PWR, WINGS VARIABLE
```

```
CH DESCRIPTION                          AVERAGE        RMS        MINIMUM      MAXIMUM

 1 CARRIAGE SPEED (M/S)              -0.2106E-03  0.2355E-02 -0.2599E-01  0.2123E-01
 2 NOZZLE TORSION [ #2 Gg] (Nm)       0.9400E+00  0.7504E+00 -0.1553E+01  0.2242E+01
 3 NOZZLE TORSION [ #3 Gg] (Nm)       0.7533E-01  0.7987E+00 -0.1133E+01  0.1963E+01
 4 CENTRE THRUST (N)                 -0.9608E+02  0.6811E+01 -0.1147E+03 -0.7933E+02
 5 CENTRE TORQUE (Nm)                -0.8460E+01  0.6473E+00 -0.9887E+01 -0.7372E+01
 6 SUCT. UPPER BENDING (Nm)           0.1753E+03  0.2217E+03 -0.3001E+03  0.2915E+03
 7 SUCT. LOWER BENDING (Nm)           0.3449E+03  0.0000E+00  0.3449E+03  0.3449E+03
 8 SUCT. TORSION (Nm)                -0.4134E+03  0.0000E+00 -0.4134E+03 -0.4134E+03
 9 TOW FORCE (N)                      0.5720E+03  0.2693E+02  0.5216E+03  0.6296E+03
10 PORT SHAFT SPEED (RPS)            -0.1358E+02  0.0000E+00 -0.1358E+02 -0.1358E+02
11 CENTRE SHAFT SPEED (RPS)          -0.8605E+01  0.2997E-01 -0.8673E+01 -0.8549E+01
12 STRBRD. SHAFT SPEED (RPS)         -0.1125E+02  0.3564E-01 -0.1134E+02 -0.1115E+02
13 NOZZLE BN [#1 GAUGE] (Nm)          0.2903E+02  0.1469E+01  0.2547E+02  0.3295E+02
14 NOZZLE BN [#2 GAUGE] (Nm)          0.2409E+02  0.1542E+01  0.2038E+02  0.2767E+02
15 NOZZLE BN [#3 GAUGE] (Nm)          0.2666E+02  0.1576E+01  0.2279E+02  0.3051E+02
16 NOZZLE TORSION [ #1 Gg] (Nm)       0.4262E+00  0.8226E+00 -0.1302E+01  0.2314E+01
```

# *APPENDIX I*

## *DETAILED DATA ON THE ICE TESTS*

```
********************************************************************************
 PROGRAM TSA24       17:04:58       19-MAY-88

 INPUT FILE = TDC195.TSD

********************************************************************************


 RUN NO.   1
 NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  4806
 NO. OF DATA BLOCKS =    113       DT =  0.0200 SEC.

 PROJ. # R4034 SELF PROPULSION TESTS IN ICE
 Vs=0.5 Kts astern, Vm=0.664 m/s, 100% PWR-ALL SHAFTS, MAX.WAX
 JAMMING IN NOZZLE AT END OF RUN
 RUN STARTED AT 28-APR-1988 17:45:53

 CH. NO.  1 - CARRIAGE SPEED (M/S)
 CH. NO.  2 - NOZZLE TORSION [ #3 Gg] (Nm)
 CH. NO.  3 - CENTRE THRUST (N)
 CH. NO.  4 - CENTRE TORQUE (Nm)
 CH. NO.  5 - PORT SHAFT SPEED (RPS)
 CH. NO.  6 - CENTRE SHAFT SPEED (RPS)
 CH. NO.  7 - STRBRD. SHAFT SPEED (RPS)
 CH. NO.  8 - NOZZLE BN [#1 GAUGE] (Nm)
 CH. NO.  9 - NOZZLE BN [#2 GAUGE] (Nm)
 CH. NO. 10 - NOZZLE BN [#3 GAUGE] (Nm)
 CH. NO. 11 - NOZZLE TORSION [ #1 Gg] (Nm)
 CH. NO. 12 - NOZZLE TORSION [ #2 Gg] (Nm)

--------------------------------------------------------------------------------


 RUN NO.  10
 NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  3983
 NO. OF DATA BLOCKS =     94       DT =  0.0200 SEC.

 PROJ. # R4034 SELF PROPULSION TESTS IN ICE
 Vs=-1.5 KTS, Vm=-0.199 M/S, ASTERN , WINGS ONLY. 75% PWR, MAX WAX
 OK
 RUN STARTED AT 28-APR-1988 19:58:42



--------------------------------------------------------------------------------


 RUN NO.  11
 NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  3084
 NO. OF DATA BLOCKS =     73       DT =  0.0200 SEC.

 PROJ. # R4034 SELF PROPULSION TESTS IN ICE
 Vs=3.0 KTS, Vm=0.399 M/S, AHEAD, 75% PWR. ALL, MAX. WAX.
 OK
 RUN STARTED AT 28-APR-1988 20:06:16
```

0.066

```
------------------------------------------------------------------------

RUN NO.   4
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  2879
NO. OF DATA BLOCKS =    68       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=3.0 KTS, Vm=0.399 M/S, AHEAD, 100% PWR. ALL, MAX WAX
OK
RUN STARTED AT 28-APR-1988 18:32:51

------------------------------------------------------------------------

RUN NO.   5
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  5019
NO. OF DATA BLOCKS =   118       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=-1.5 KTS, Vm=-0.199 M/S, ASTERN, 100 % PWR.ALL, MAX WAX
K
RUN STARTED AT 28-APR-1988 18:39:53

------------------------------------------------------------------------

RUN NO.   6
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  2445
NO. OF DATA BLOCKS =    58       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=5.0 KTS. Vm=0.664 M/S. AHEAD, 100 % PWR. ALL. MAX. WAX
OK
RUN STARTED AT 28-APR-1988 18:47:58

------------------------------------------------------------------------

RUN NO.   7
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  1576
NO. OF DATA BLOCKS =    37       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=0, ZERO SPEED STATS.
OK
RUN STARTED AT 28-APR-1988 18:58:09

------------------------------------------------------------------------
```

```
RUN NO.   8
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  8287
NO. OF DATA BLOCKS =   195      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=-0.5 KTS, Vm=-0.066 M/S, ASTERN, 100 % PWR, ALL, MAX. WAX.
OK
RUN STARTED AT 28-APR-1988 19:05:19



------------------------------------------------------------------------


RUN NO.   9
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  8254
NO. OF DATA BLOCKS =   194      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=1.0 KTS, Vm=0.133 M/S, AHEAD, 75% PWR. ALL, MAX. WAX
OK
RUN STARTED AT 28-APR-1988 19:44:12



------------------------------------------------------------------------



************************************************************************

TOTAL NUMBER OF RUNS IN TDC195.TSD =     26

************************************************************************
```

```
------------------------------------------------------------------------------


RUN NO.  12
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =  1192
NO. OF DATA BLOCKS =    28      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=0, ZERO SPEED STATS
OK
RUN STARTED AT 28-APR-1988 20:16:31


------------------------------------------------------------------------------


RUN NO.  13
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =  5303
NO. OF DATA BLOCKS =   125      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=-0.5 KTS, Vm=-0.066 M/S, ASTERN, 50% PWR. WINGS AFT, CENTRE FWD. MAX. WA
OK
RUN STARTED AT 28-APR-1988 20:23:00


------------------------------------------------------------------------------


RUN NO.  14
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =  8043
NO. OF DATA BLOCKS =   139      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=1.0 KTS, Vm=0.133 M/S, AHEAD, 50% PWR, ALL, MAX.WAX
OK
RUN STARTED AT 28-APR-1988 20:36:49


------------------------------------------------------------------------------


RUN NO.  15
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =  4310
NO. OF DATA BLOCKS =   102      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
[illegible]s=-1.5 KTS. Vm=-0.199 M/S, ASTERN, 50 % PWR, WINGS ONLY, MAX. WAX
[illegible]K
RUN STARTED AT 28-APR-1988 20:44:47


------------------------------------------------------------------------------
```

```
UN NO.  16
O. OF CHANNELS =  12        NO. OF SAMPLES PER CHANNEL =  1304
O. OF DATA BLOCKS =     31        DT =  0.0200 SEC.

ROJ. # R4034 SELF PROPULSION TESTS IN ICE
ERO SPEED STATS
K
UN STARTED AT 28-APR-1988 20:52:53



-----------------------------------------------------------------------------


UN NO.  17
O. OF CHANNELS =  12        NO. OF SAMPLES PER CHANNEL =  2794
O. OF DATA BLOCKS =     66        DT =  0.0200 SEC.

ROJ. # R4034 SELF PROPULSION TESTS IN ICE
s=3.0 KTS, Vm=0.399 M/S, 80% DRAFT, 100%PWR, ALL, MAX. WAX
K
UN STARTED AT 28-APR-1988 22:47:28



-----------------------------------------------------------------------------


UN NO.  18
O. OF CHANNELS =  12        NO. OF SAMPLES PER CHANNEL =  4012
O. OF DATA BLOCKS =     95        DT =  0.0200 SEC.

ROJ. # R4034 SELF PROPULSION TESTS IN ICE
s=-1.5 KTS, Vm=-0.199 M/S. ASTERN. 80% DRAFT. 100% PWR, WINGS ONLY. MAX WA
K
UN STARTED AT 28-APR-1988 22:56:07



-----------------------------------------------------------------------------


UN NO.  19
O. OF CHANNELS =  12        NO. OF SAMPLES PER CHANNEL =  3287
O. OF DATA BLOCKS =     78        DT =  0.0200 SEC.

ROJ. # R4034 SELF PROPULSION TESTS IN ICE
s=3.0 KTS, Vm=0.399 M/S, AHEAD, 80% DRAFT, 100%PWR ALL, 90% WAX
K
UN STARTED AT 28-APR-1988 23:17:21



-----------------------------------------------------------------------------


UN NO.   2
O. OF CHANNELS =  12        NO. OF SAMPLES PER CHANNEL =  8082
```

```
NO. OF DATA BLOCKS =   190      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=1.0 KTS, Vm=0.133 M/S, AHEAD, 100 % PWR. ALL SHAFTS, MAX. WAX.
OK
RUN STARTED AT 28-APR-1988 18:09:41


----------------------------------------------------------------------------


RUN NO.  20
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =  1707
NO. OF DATA BLOCKS =    41      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=10.0 KTS, Vm=1.3 M/S, AHEAD, 80% DRFT, 100%PWR, ALL, 60% WAX
OK
RUN STARTED AT 28-APR-1988 23:44:53


----------------------------------------------------------------------------


RUN NO.  21
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =   492
NO. OF DATA BLOCKS =    12      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. A. [END OF TEST FRICTION RUNS]
OK
RUN STARTED AT 29-APR-1988 00:45:45


----------------------------------------------------------------------------


RUN NO.  22
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =   581
NO. OF DATA BLOCKS =    14      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. B.
OK
RUN STARTED AT 29-APR-1988 00:46:52


----------------------------------------------------------------------------


RUN NO.  23
NO. OF CHANNELS =  12      NO. OF SAMPLES PER CHANNEL =   740
NO. OF DATA BLOCKS =    18      DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. C
```

```
OK
RUN STARTED AT 29-APR-1988 00:47:58


------------------------------------------------------------------------


RUN NO.  24
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =    678
NO. OF DATA BLOCKS =    16       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. D
OK
RUN STARTED AT 29-APR-1988 00:49:11


------------------------------------------------------------------------


RUN NO.  25
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  1071
NO. OF DATA BLOCKS =    26       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. E.
OK
RUN STARTED AT 29-APR-1988 00:50:48


------------------------------------------------------------------------


RUN NO.  26
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =    577
NO. OF DATA BLOCKS =    14       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
FRIC. PNT. F
OK
RUN STARTED AT 29-APR-1988 00:52:02


------------------------------------------------------------------------


RUN NO.   3
NO. OF CHANNELS =  12       NO. OF SAMPLES PER CHANNEL =  6268
NO. OF DATA BLOCKS =   147       DT =  0.0200 SEC.

PROJ. # R4034 SELF PROPULSION TESTS IN ICE
Vs=-1.0 KTS, Vm=-0.133 M/S, ASTERN, 100% PWR. ALL, MAX. WAX
OK
RUN STARTED AT 28-APR-1988 18:21:57
```

# APPENDIX J

## DETAILED DATA ON THE MODEL OF LSSL

## TABLE III

### Thrust/Power Relationship for the Existing Propeller (Center Shaft)*

| Mean Thrust Tonnes | Mean Power kW | Ship Speed m/s | T/ kW |
|---|---|---|---|
| 70 | 5840 | 0.00 | 0.012 |
| 65 | 5040 | 6.12 | 0.013 |
| 62 | 4180 | 3.99 | 0.015 |
| 61 | 5022 | 3.88 | 0.013 |
| 58 | 4602 | 2.75 | 0.013 |
| 62 | 4960 | 6.18 | 0.013 |
| Extrapolation to MCR power of 5,886 kW | | | |
| 70.5 | 5886 | | |
| Extrapolation to MCR power of 6,622 kW | | | |
| 78.7 | 6,622 | | |

---

* After action report; CCGS Louis S. St. Laurent Arctic Probe; May 1977 prepared by: Operation and Technical Divisions, Fleet Systems, CCG 1978.

## TABLE II

## Power Plant Characteristics

Transmission Type electric

Maximum power developed by the motors 9000HP

Shaftline transmission efficiency 0.98

MAX RPM = 193

MIN RPM = 138

Torque Limite $Q_{MAX}$ = 458 kNm

Overload condition = 1.15 MCR on torque

Maximum dia of propeller (limit) 16' (4.88 m)

Blade Material: Nickel vanadium steel/Superstone 70

Shaft submergence for cavitation check 19.5' = 5.94 m

## TABLE III

## Data used for This Study

Water properties

$\rho$ = 1025 kg/m$^3$

$P_{VAP}$ = 608 Pa at 5°C

TABLE I

## Principal Characteristics of CCGS Louis S. St. Laurent

Built 1969 Canadian Vickers, Montreal ASPPR ice class 4.

LOA - 11.7 m ?
$B_{MAX}$ - 24.38
$T_{MAX}$ - 9.45 m
D - 14,280 tonnes
MAX SPEED, (estimated) - 17.7 knots
MCR - 24,000 HP
Number of shafts - 3
Crew - 81
Depth for Cavitation - 29.5' (9 m)

$C_B$ = 0.591
$C_{WL}$ = 0.776
$C_M$ = 0.85

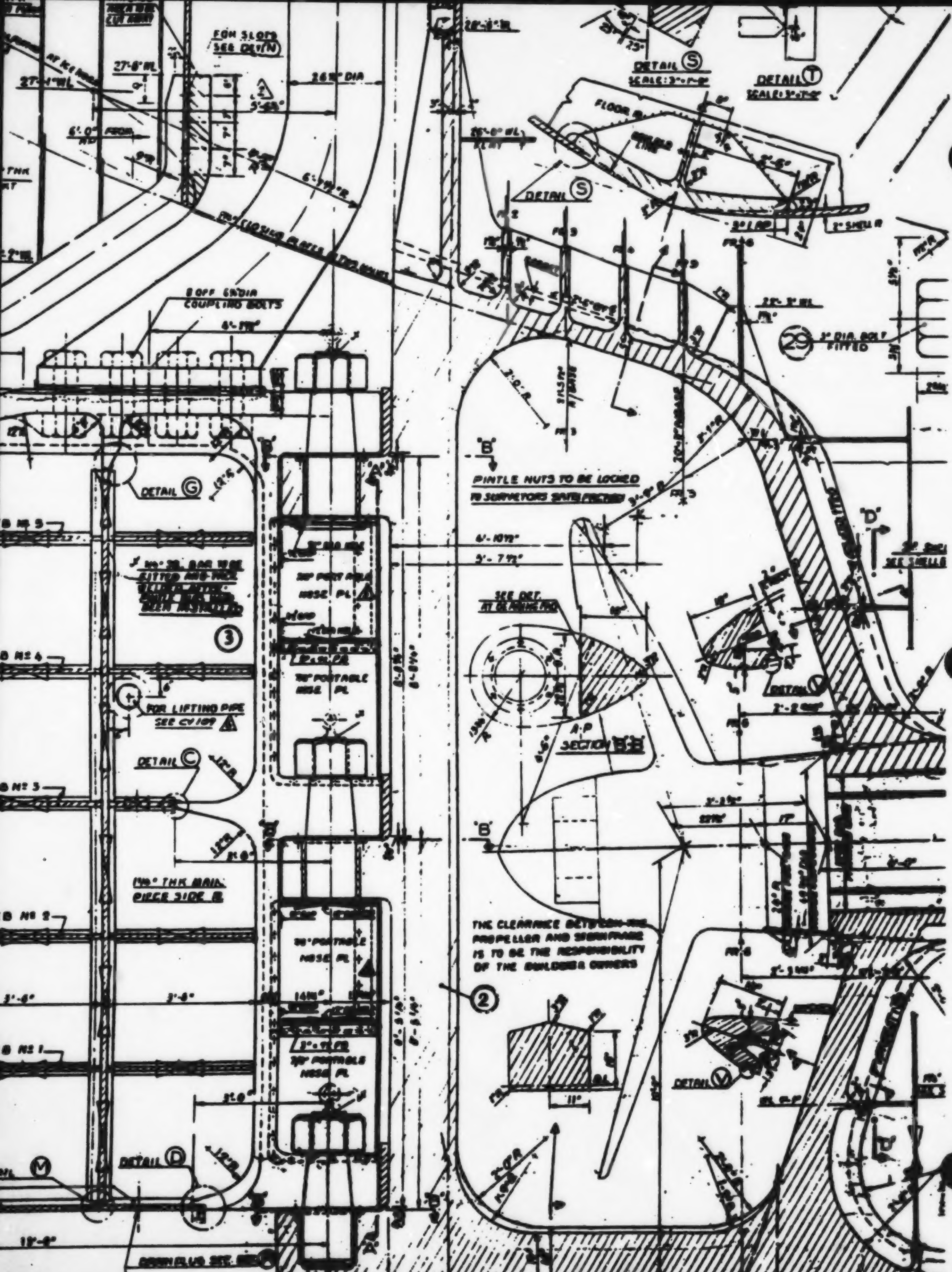
Existing propellers' data:

DIA - 15.0 ft. (4.57 m)
P/D - 0.749
DAR - 0.552
RPM - 187 design/193 overload; at free running
- 133 design/138 overload; bollard

Bollard thrust - 76 tonnes
Propeller turning clockwise

Recommended propeller data:

DIA - 14.5 ft (4.42 m)
P/D - 0.790
DAR - 0.550
RPM - 193 free running/148 bollard
Bollard thrust - 81 tonnes


FOR SLOTS SEE DET (N)
27'-8" WL
27'-1" WL
6'-0" FROM
26½" DIA
6'-7½" R
CLOSING PLATES FITTED BOLTS
8 OFF 6⅞" DIA COUPLING BOLTS
6'-1½"
26'-8" WL
25'-0" WL
DETAIL (S)
SCALE: 3" = 1'-0"
DETAIL (T)
SCALE: 3" = 1'-0"
FLOOR PL
25°
3" LAP
2" SHELL PL
FR 2
FR 3
FR 4
FR 5
FR 6
22'-3" WL
29
1" DIA. BOLT FITTED
3'-0" R
'B'
PINTLE NUTS TO BE LOCKED TO SURVEYORS SATISFACTION
6'-10½"
5'-7½"
'D'
SEE SHELL
SEE DET. AT BEARING PAD
A.P
SECTION 'B'-'B'
DETAIL (V)
DETAIL (G)
12'-6"
FOR LIFTING PIPE SEE CV 109
DETAIL (C)
3
1⅝" THK MAIN PIECE SIDE B
PORTABLE NOSE PL
NOSE PL
THE CLEARANCE BETWEEN THE PROPELLER AND STERNFRAME IS TO BE THE RESPONSIBILITY OF THE BUILDERS & OWNERS
2
11"
3'-6"
3'-0"
DETAIL (D)
DETAIL (M)
13'-6"
'A'
'B' № 5
'B' № 4
'B' № 3
'B' № 2
'B' № 1

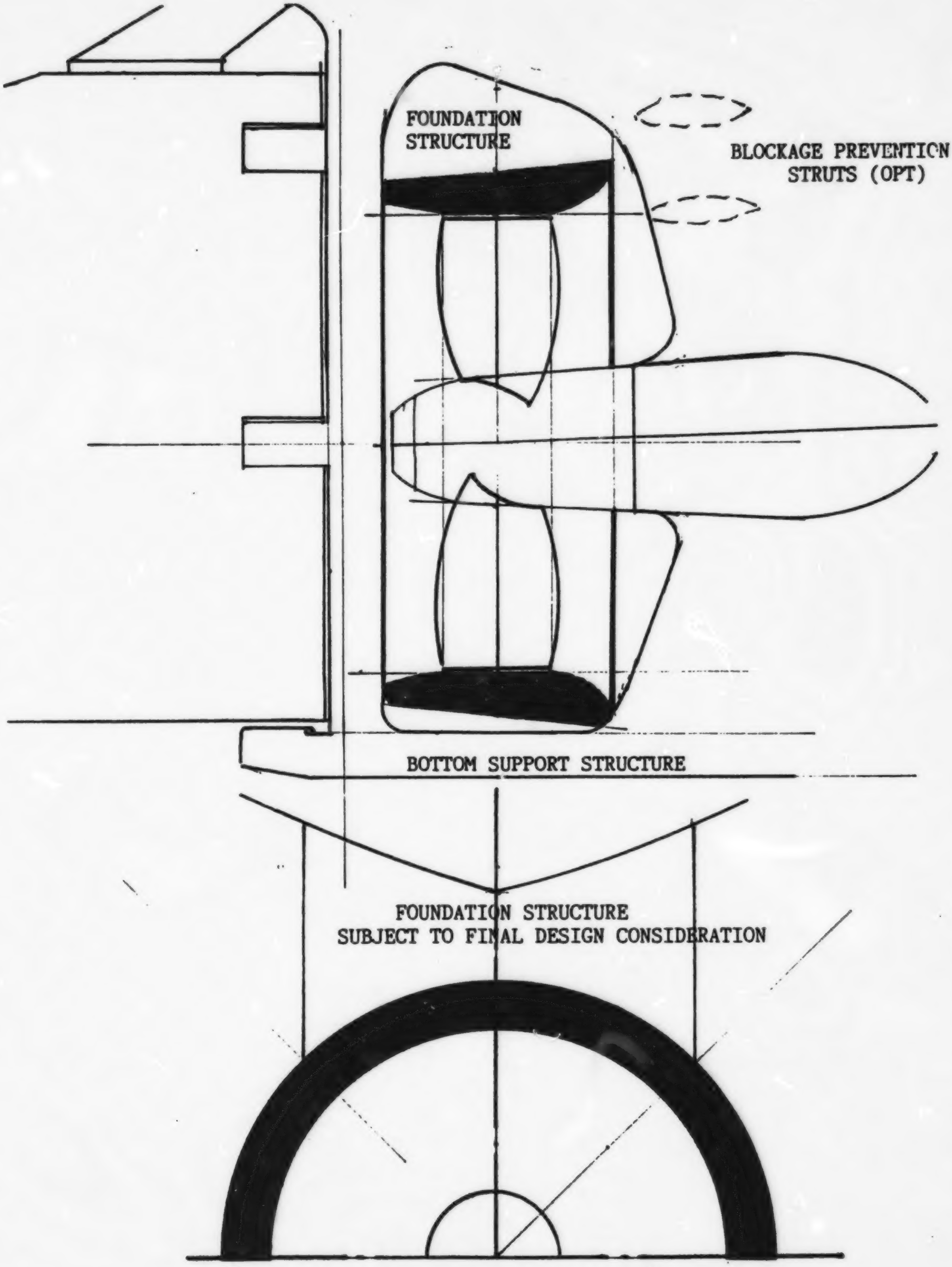
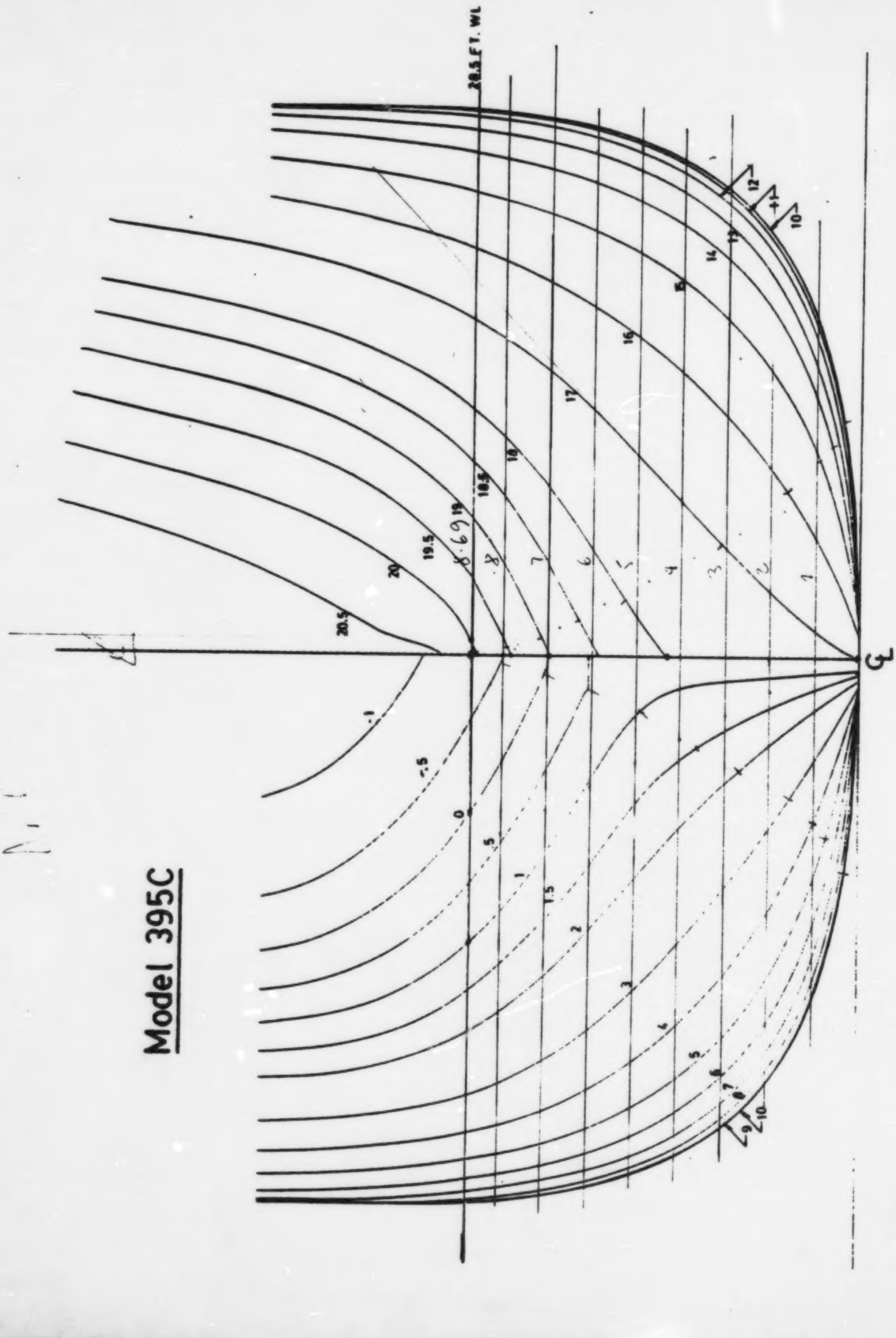

FOUNDATION STRUCTURE
BLOCKAGE PREVENTION STRUTS (OPT)
BOTTOM SUPPORT STRUCTURE
FOUNDATION STRUCTURE SUBJECT TO FINAL DESIGN CONSIDERATION

FIGURE 8 4.20 m Dia PROPELLER AND NOZZLE

ARCTIC RESEARCH AND DEVELOPMENT


28.5 FT. WL
12
11
10
13
14
15
16
17
18
18.5
19
19.5
20
20.5
8.69
8
7
6
5
4
3
2
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.5
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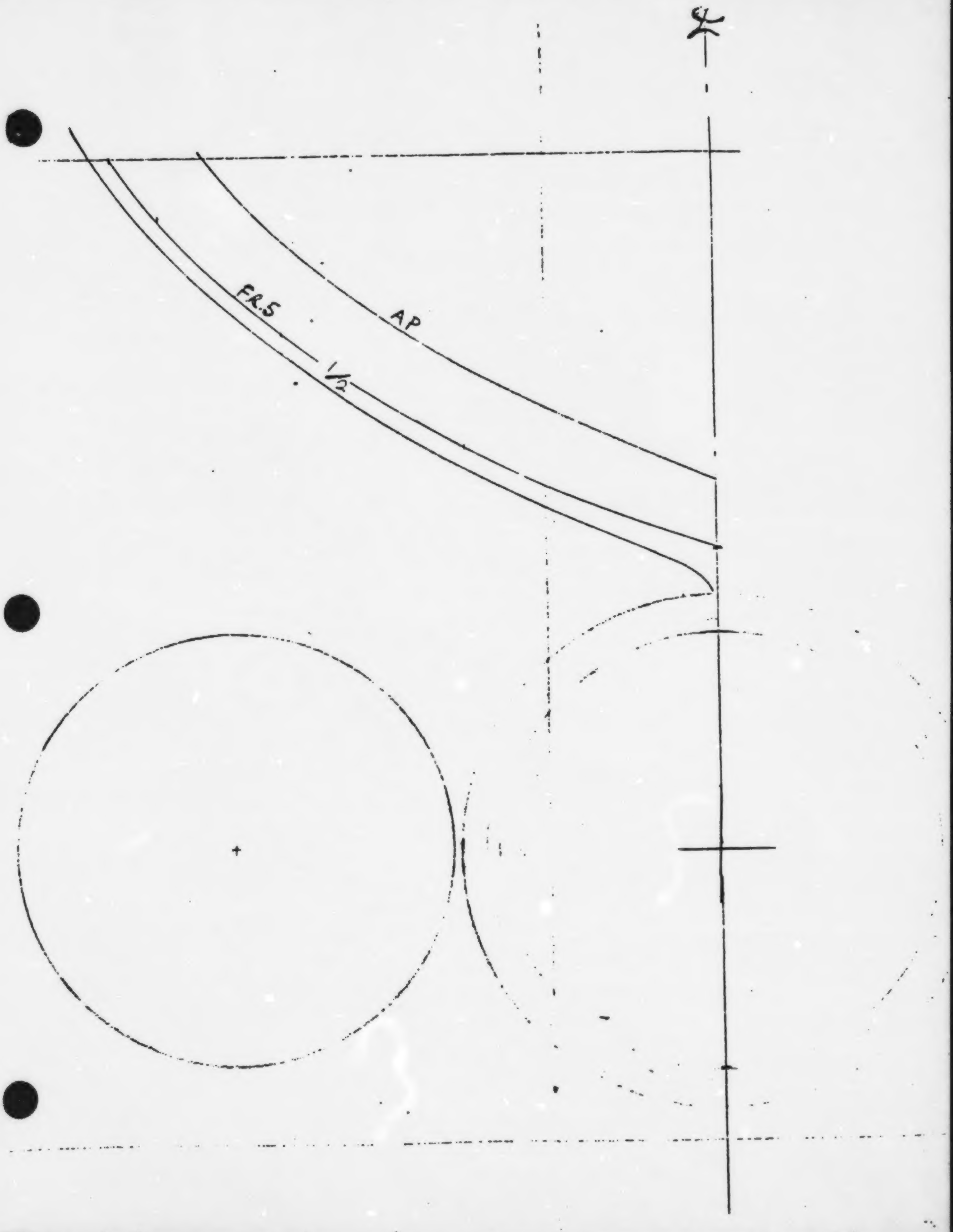
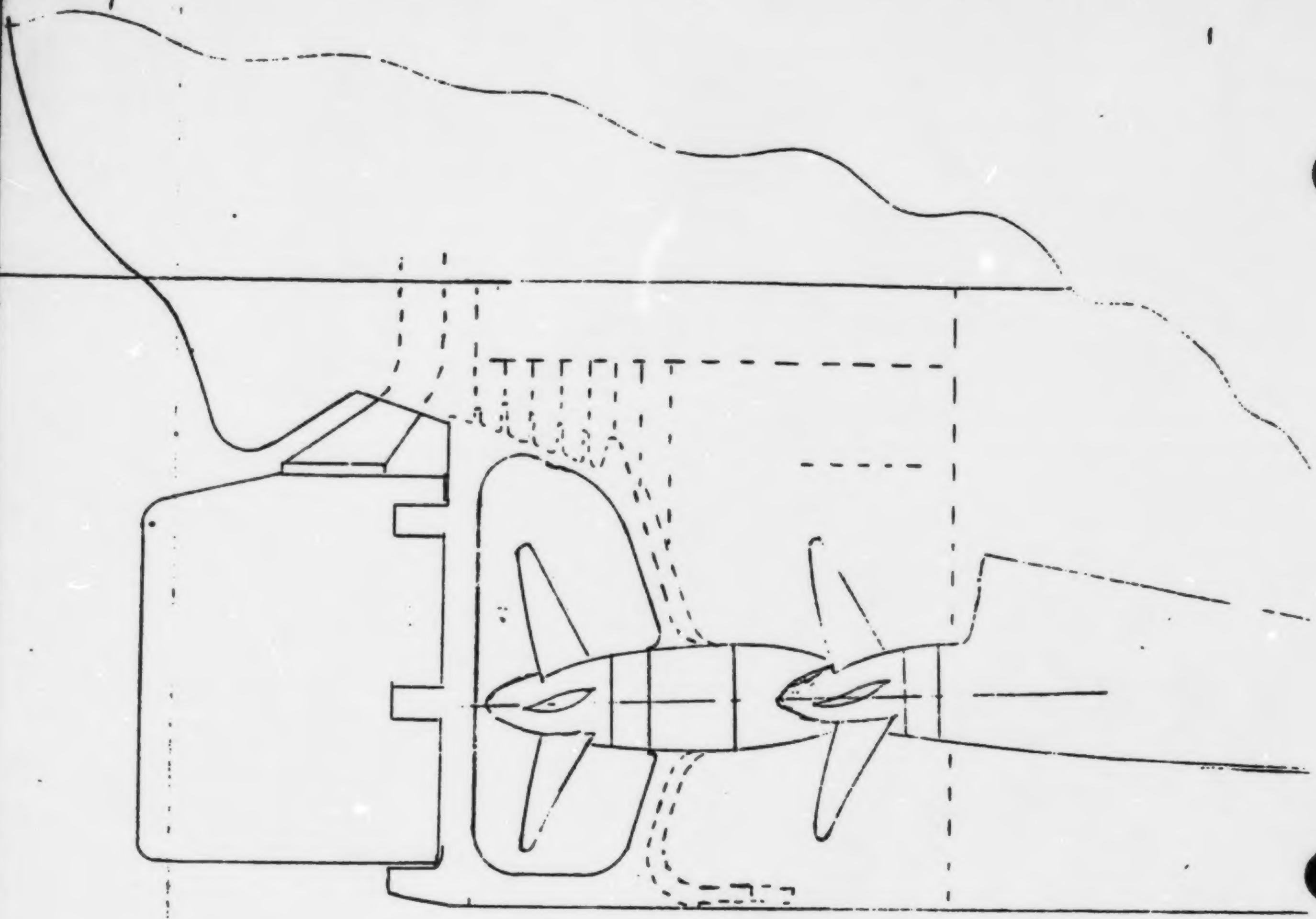
1.5
2
3
4
5
6
7
8
9
10

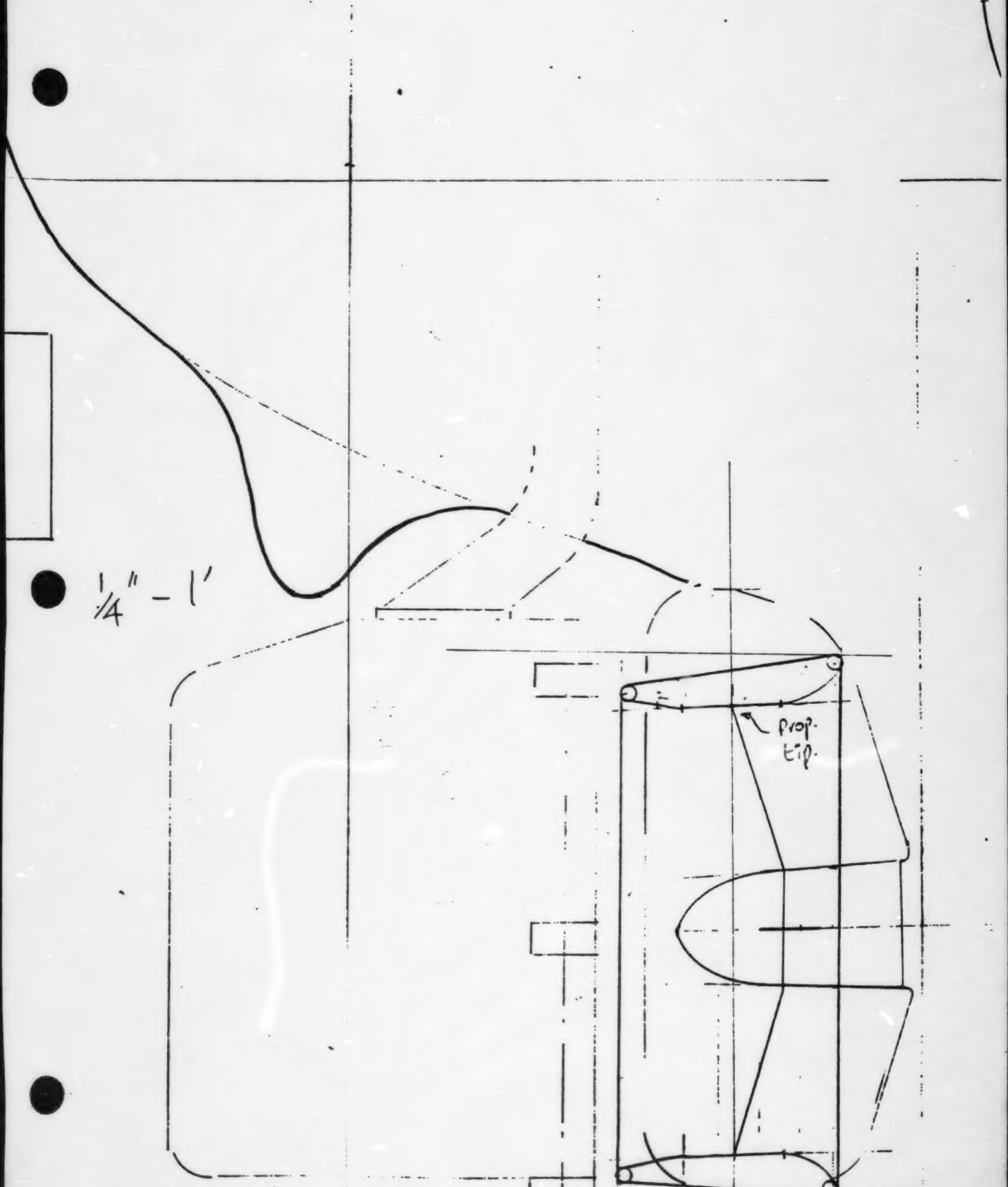
Model 395C

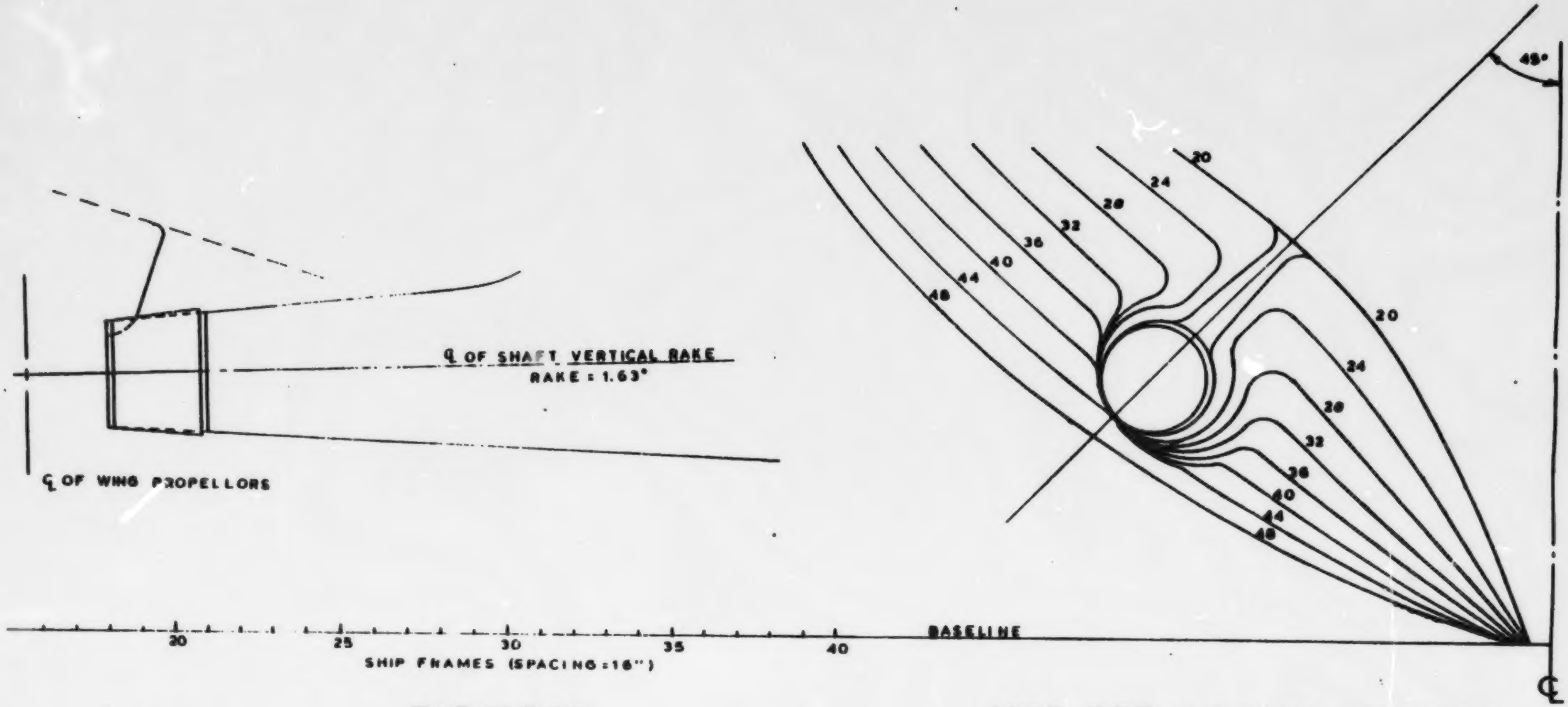

℄
FR.5
AP
1/2



1/8" - 1'

1/4" - 1'



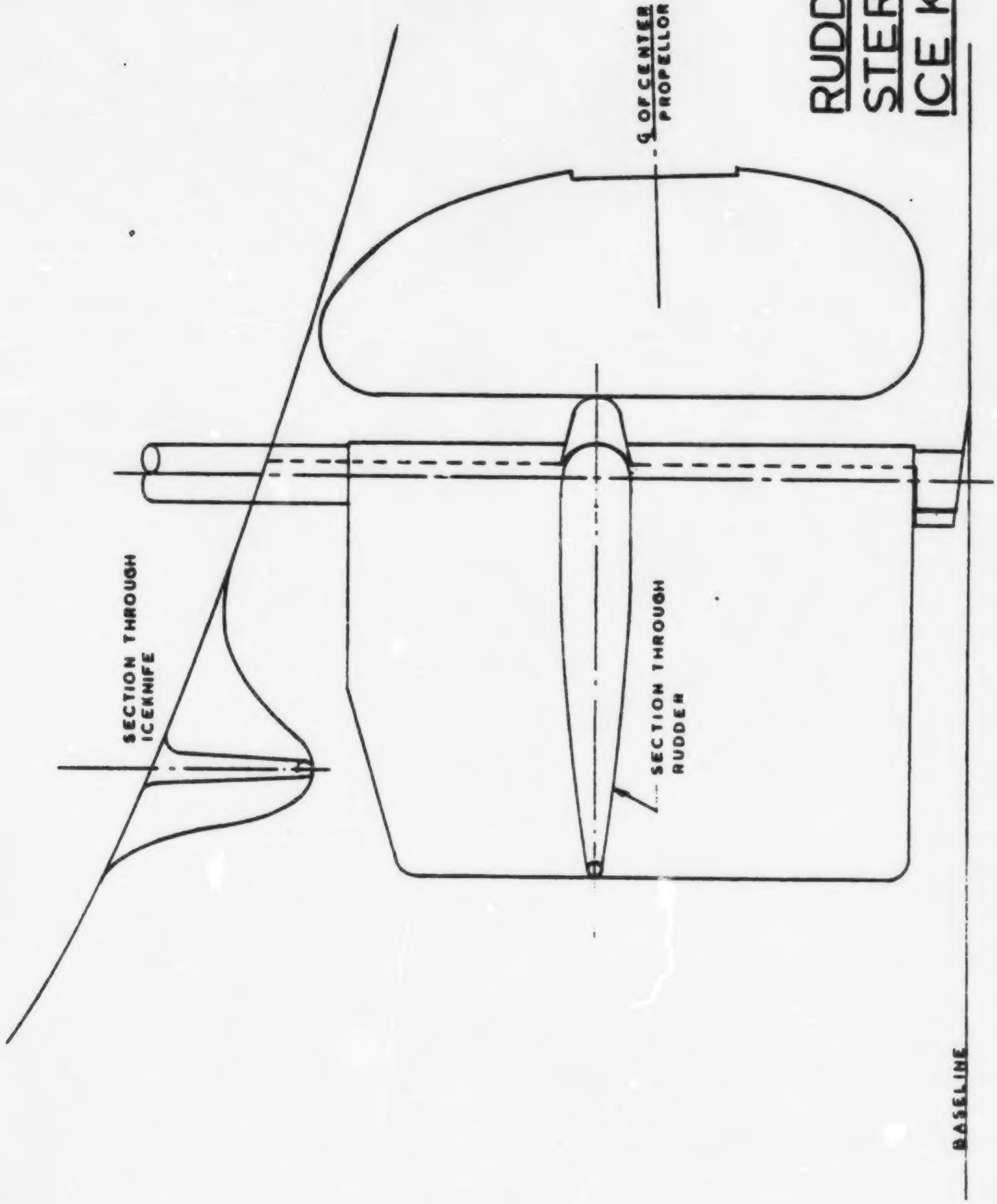


ELEVATION

PORT SIDE - LOOKING FORWARD

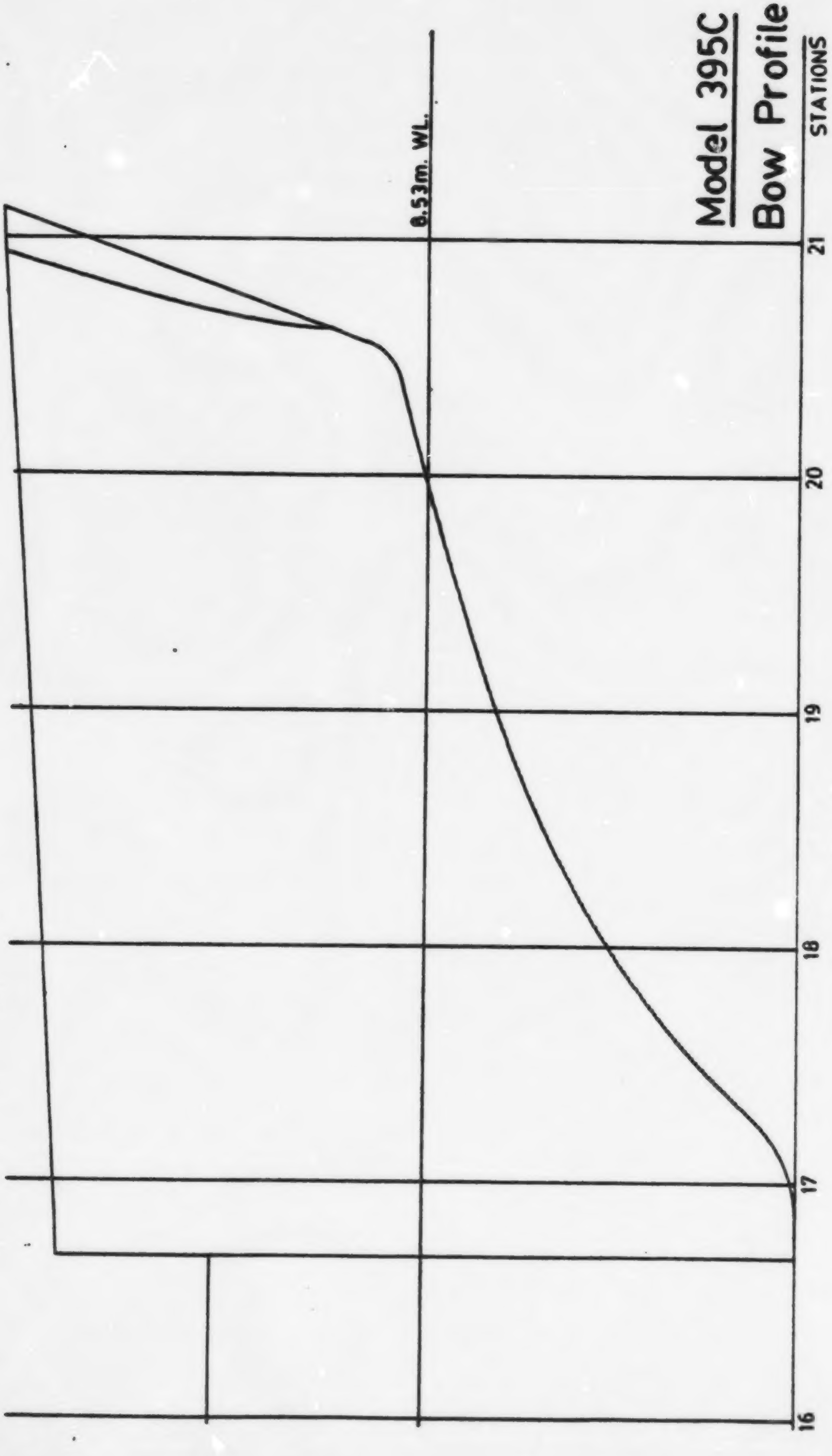
BOSSING

RUDDER
STERNFRAME
ICE KNIFE



PROFILE

Figure 2



Model 395C
Bow Profile

## TABLE 1

## SUMMARY OF MODEL CONDITIONS

## MODEL 395C

### Model Description

| | |
|---|---|
| Scale | 1/15 |
| Material | Foam, Glass Mat and Epoxy, Gelcoat Final Paint Finish, Kevlar at Waterline on Bow |

### Turbulence Stimulators

| | |
|---|---|
| Type | Tripwire |
| Location | 5 percent LPP aft of Fore perpendicular at waterline, parallel to bow profile |

### Appendages

| | |
|---|---|
| Number of Rudders | 1 |
| Rudder Stock | 0m Forward of aft Perpendicular |
| Span | 5.572m |
| Chord (Constant) | 4.752m |
| Thickness Chord Ratio | 0.14 |
| Number of Propellers | 3 |
| Number of Propeller Shafts | 3 |
| Shaft Rake, Upwards (Centre) | 1.90 degrees |
| (Wings) | 1.63 |
| Shaft Rake, Outwards (Centre) | 0 |
| (Wings) | 3.71 |
| Type of Shaft | Enclosed |
| Type of Shaft Support (Centre) | Stub Bossing |
| (Wings) | Full Bossing, 1.314m Diameter at aft end<br>9.48m Long Along Shaft Centreline |
| Propeller Centres (Centre) | 3.067m Above Baseline<br>1.956m fwd. of AP |
| (Wings) | 5.029m From Centreline<br>3.149m above baseline<br>6.248m fwd. of AP |

### Model Test Condition - FULL SCALE

| Model Number | Draught Midships | Trim By Stern | Displacement (Tonnes, S.W.) |
|---|---|---|---|
| 395C | 8.53 (28 ft.) | 0.0 | 12713 |
| 395C | 6.82 (22.39 ft.) | 0.0 | |

## TABLE 2

## MODEL 395C -- GERMAN & MILNE BOW

## DESIGN DRAUGHT -- 8.53 m. (28.0 ft.)

### HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 15.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 7.112 |
| LENGTH ON WATERLINE (LWL), m | 7.355 |
| WATERLINE BEAM AT MIDSHIPS, m | 1.620 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 1.621 |
| MAXIMUM WATERLINE BEAM, m | 1.622 |
| DRAUGHT AT MIDSHIPS, m | 0.569 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.569 |
| MAXIMUM DRAUGHT, m | 0.569 |
| DRAUGHT ABOVE DATUM, m | 0.569 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -0.142 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 0.142 |
| TO, FORWARD OF MIDSHIPS, m | -0.142 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.783 |
| AREA OF MAXIMUM STATION, SQ. m | 0.784 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.191 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.374 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 1.185 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.332 |
| WETTED SURFACE AREA, SQ. m | 12.914 |
| VOLUME OF DISPLACEMENT, CU. m | 3.683 |
| DISPLACEMENT, kg OF FRESH WATER | 3679.0 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.217 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.591 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.390 |
| AREA OF WATERLINE PLANE, SQ. m | 9.057 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.416 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 7.565 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.243 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.295 |
| AREA OF PROFILE PLANE, SQ. m | 3.580 |

## TABLE 3

## MODEL 395C -- GERMAN & MILNE BOW

## DESIGN DRAUGHT -- 8.53 m. (28.0 ft.)

## HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 106.68 |
| LENGTH ON WATERLINE (LWL), m | 110.32 |
| | |
| WATERLINE BEAM AT MIDSHIPS, m | 24.29 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 24.32 |
| MAXIMUM WATERLINE BEAM, m | 24.33 |
| | |
| DRAUGHT AT MIDSHIPS, m | 8.53 |
| DRAUGHT AT MAXIMUM SECTION, m | 8.53 |
| MAXIMUM DRAUGHT, m | 8.53 |
| DRAUGHT ABOVE DATUM, m | 8.53 |
| | |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -2.13 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 2.13 |
| TO, FORWARD OF MIDSHIPS, m | -2.13 |
| AREA OF MIDSHIPS STATION, SQ. m | 176.17 |
| AREA OF MAXIMUM STATION, SQ. m | 176.44 |
| | |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -2.87 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -20.61 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 17.78 |
| CENTRE OF BUOYANCY ABOVE DATUM, m | 4.97 |
| | |
| WETTED SURFACE AREA, SQ. m | 2905.68 |
| VOLUME OF DISPLACEMENT, CU. m | 12430.99 |
| DISPLACEMENT, t OF SALT WATER | 12753. |
| | |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -3.25 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -23.87 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 20.85 |
| | |
| AREA OF WATERLINE PLANE, SQ. m | 2037.90 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 6.24 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 113.48 |
| | |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -3.65 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 4.43 |
| AREA OF PROFILE PLANE, SQ. m | 305.56 |

## TABLE 4

## MODEL 395C -- GERMAN & MILNE BOW

## DESIGN DRAUGHT -- 8.53 m. (28.0 ft.)

## COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH ON WATERLINE
BEAM AT MAXIMUM STATION
DRAUGHT AT MAXIMUM STATION

| | |
|---|---|
| L/B | 4.536 |
| L/T | 12.927 |
| B/T | 2.850 |
| | |
| LWL (AFT BODY)/L | 0.518 |
| LWL (FORE BODY)/L | 0.482 |
| | |
| CB | 0.543 |
| CB OF THE AFT BODY | 0.564 |
| CB OF THE FORE BODY | 0.520 |
| CM | 0.849 |
| CX | 0.850 |
| CP | 0.639 |
| LCB %L FORWARD OF MIDSHIPS | -2.602 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -18.679 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 16.115 |
| | |
| CW | 0.760 |
| CW OF THE AFT BODY | 0.790 |
| CW OF THE FORE BODY | 0.726 |
| CIT | 0.587 |
| CIL | 0.518 |
| LCF %L FORWARD OF MIDSHIPS | -2.950 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -21.635 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 18.898 |
| | |
| BM/B | 0.257 |
| BML/L | 1.029 |
| | |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 1.050 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.368 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 4.762 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 5.415 |
| BM - DISPLACEMENT RATIO | 0.269 |
| BML - DISPLACEMENT RATIO | 4.899 |
| | |
| AREA OF PROFILE PLANE/LT | 0.856 |
| CLR %L FORWARD OF MIDSHIPS | -3.309 |

## TABLE 5

## MODEL 395C -- GERMAN & MILNE BOW

## DESIGN DRAUGHT -- 8.53 m. (28.0 ft.)

## SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.033 | 0.269 | 0.188 |
| 1 | 0.188 | 0.515 | 1.000 |
| 2 | 0.412 | 0.681 | 1.000 |
| 3 | 0.595 | 0.800 | 1.000 |
| 4 | 0.731 | 0.869 | 1.000 |
| 5 | 0.831 | 0.919 | 1.000 |
| 6 | 0.899 | 0.955 | 1.000 |
| 7 | 0.947 | 0.978 | 1.000 |
| 8 | 0.979 | 0.994 | 1.000 |
| 9 | 0.996 | 1.000 | 1.000 |
| 10 | 0.998 | 0.999 | 1.000 |
| 11 | 0.989 | 0.996 | 1.000 |
| 12 | 0.969 | 0.985 | 1.000 |
| 13 | 0.927 | 0.960 | 1.000 |
| 14 | 0.863 | 0.918 | 1.000 |
| 15 | 0.754 | 0.845 | 1.000 |
| 16 | 0.581 | 0.740 | 1.000 |
| 17 | 0.358 | 0.607 | 0.985 |
| 18 | 0.138 | 0.440 | 0.488 |
| 19 | 0.028 | 0.235 | 0.187 |
| 20 | 0.000 | 0.000 | 0.000 |

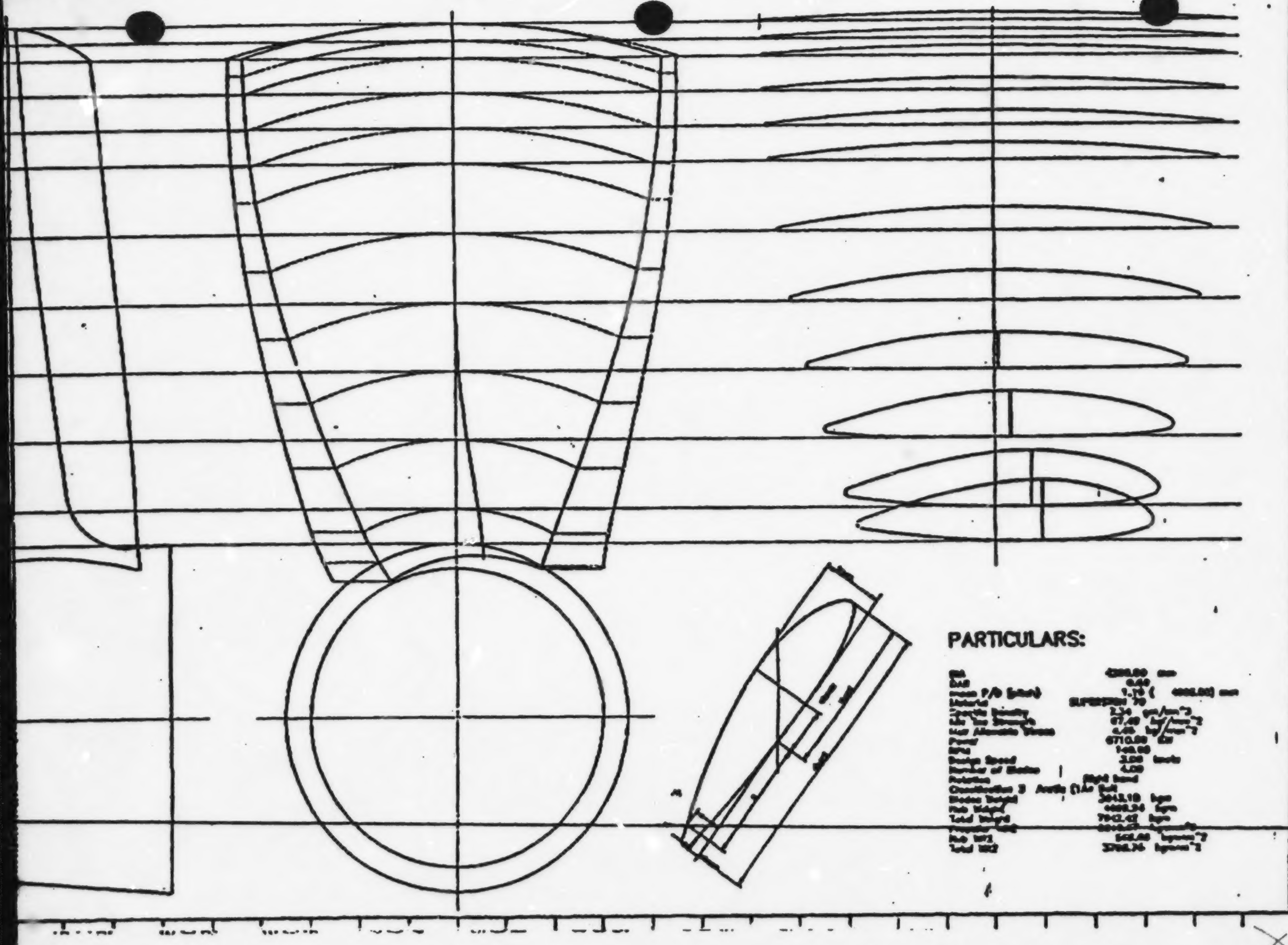
AFT END OF WATERLINE IS AT -0.713
FORWARD END OF WATERLINE IS AT 19.969

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

## TABLE 7

## WING PROPELLER DESCRIPTION

| | Wings |
|---|---|
| Propeller Number | 86, 88 |
| Design Description | Modified Wageningen B-Screw |
| Scale | 1/15 |
| Diameter (m) | 4.57 |
| Pitch at 0.7R (m) | 3.199 |
| P/D | 0.700 |
| Bar | 0.552 |
| Number of Blades | 4 |
| Direction of Rotation | Outward Turning |
| Rake (Degrees) | 7.63 |
| Bossing Length (m) | 1.143 |
| Bossing Diameter (fwd) (m) | 1.162 |
| Bossing Diameter (aft) (m) | 1.016 |



## PARTICULARS:

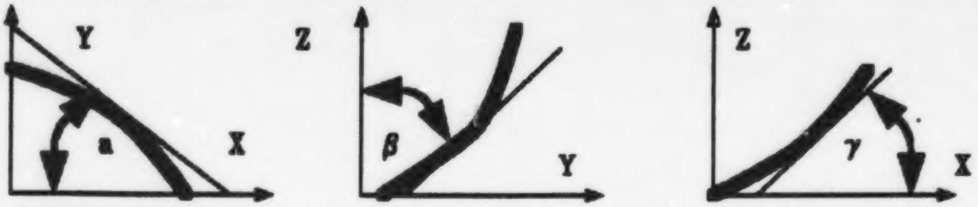
| | |
|---|---|
| Dia | 4200.00 mm |
| EAR | 0.60 |
| mean P/D (pitch) | 1.[illegible] ( [illegible]) mm |
| Material | SUPERSTON 70 |
| Specific Density | 7.[illegible] gm/cm^3 |
| Ult Ten Strength | 67.[illegible] kgf/mm^2 |
| Max Allowable Stress | 4.[illegible] kgf/mm^2 |
| Power | 6710.00 kW |
| RPM | 1[illegible].00 |
| Design Speed | [illegible].00 knots |
| Number of Blades | 4.00 |
| Rotation | Right hand |
| Classification | 3 Arctic (1A Sw) |
| Blades Weight | 3[illegible]12.18 kgs |
| Hub Weight | [illegible].34 kgs |
| Total Weight | 79[illegible].42 kgs |
| Propeller [illegible] | [illegible] |
| Hub WR2 | [illegible] kgm*m^2 |
| Total WR2 | 37[illegible] kgm*m^2 |

## OPELLER BLADE OFFSETS

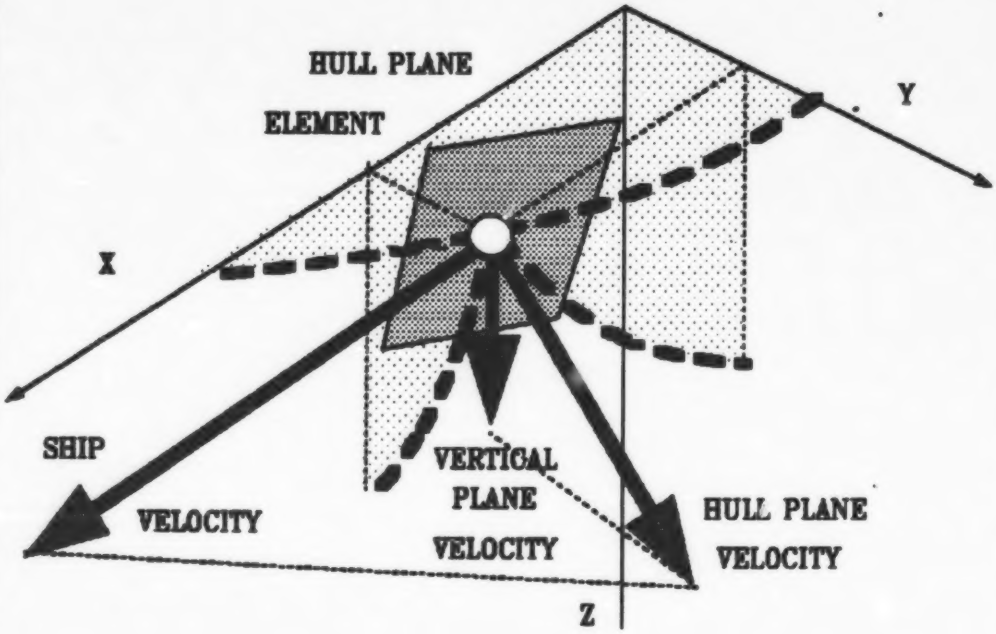
```
25.0  PITCH= 4623.2  CHORD=  894.6 X-LEAD=    472.1 T-MAX=    184.4 X-TMAX=    141.1
422.5 -366.2 -309.8 -197.1  -84.4   28.4  141.1  207.3  273.5  339.7  405.9  439.0  472.
41.90  34.11  26.62  14.50   5.64   1.35   0.00   0.50   3.61  10.79  23.63  33.05  49.1
65.05  82.53 101.84 135.22 160.05 178.02 184.42 180.91 170.28 153.52 127.12 105.56  72.4

30.0  PITCH= 4748.1  CHORD=  950.0 X-LEAD=    487.8 T-MAX=    168.9 X-TMAX=    109.1
462.3 -405.2 -348.0 -233.7 -119.5   -5.2  109.1  184.8  260.5  336.3  412.0  449.9  487.
34.00  26.39  19.66   9.19   2.98   0.49   0.00   0.40   2.18   7.42  17.56  25.95  43.1
55.47  72.49  90.67 122.00 146.32 163.26 168.92 165.63 155.18 139.77 114.68  94.56  64.5

40.0  PITCH= 4948.0  CHORD= 1036.5 X-LEAD=    534.1 T-MAX=    140.0 X=TMAX=     47.9
522.4 -465.4 -408.4 -294.3 -180.3  -66.2   47.9  145.1  242.3  339.6  436.8  485.4  534.
17.86  11.83   7.67   2.60   0.54   0.00   0.00   0.00   0.40   2.30   7.75  13.24  26.5
36.13  52.14  68.54  98.21 121.23 135.67 139.99 136.64 127.40 112.99  89.56  70.89  44.8

50.0  PITCH= 5008.0  CHORD= 1153.5 X-LEAD=    578.3 T-MAX=    113.8 X-TMAX=     11.5
575.3 -516.6 -457.9 -340.5 -223.2 -105.8   11.5  124.9  238.2  351.6  464.9  521.6  578.
 5.14   3.25   1.87   0.39   0.00   0.00   0.00   0.00   0.00   0.33   2.08   4.92  12.5
20.45  36.93  52.34  79.13  98.60 110.25 113.80 110.95 102.77  89.30  67.02  50.34  27.9

60.0  PITCH= 5008.0  CHORD= 1240.5 X-LEAD=    620.2 T-MAX=     90.4 X-TMAX=      0.2
620.2 -558.2 -496.1 -372.0 -247.9 -123.8    0.2  124.2  248.2  372.2  496.2  558.2  620.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.05   0.52   2.9
12.58  27.24  40.47  62.48  78.13  87.36  90.37  87.96  80.96  68.59  48.56  34.26  15.5

70.0  PITCH= 5008.0  CHORD= 1312.9 X-LEAD=    656.5 T-MAX=     69.7 X-TMAX=      0.0
656.5 -590.8 -525.2 -393.9 -262.6 -131.3    0.0  131.3  262.6  393.9  525.2  590.8  656.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
10.07  21.40  31.53  48.22  60.15  67.30  69.68  67.75  61.70  50.85  34.75  24.00  10.0

80.0  PITCH= 5008.0  CHORD= 1365.2 X-LEAD=    682.6 T-MAX=     51.7 X-TMAX=      0.0
682.6 -614.3 -546.1 -409.6 -273.0 -136.5    0.0  136.5  273.0  409.6  546.1  614.3  682.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 7.80  16.15  23.62  35.93  44.72  49.99  51.75  50.14  45.24  36.56  24.35  16.71   7.8

85.0  PITCH= 5008.0  CHORD= 1384.7 X-LEAD=    692.4 T-MAX=     43.8 X-TMAX=      0.0
692.4 -623.1 -553.9 -415.4 -276.9 -138.5    0.0  138.5  276.9  415.4  553.9  623.1  692.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 6.75  13.79  20.09  30.47  37.88  42.33  43.81  42.38  38.07  30.67  20.31  13.98   6.7

90.0  PITCH= 5008.0  CHORD= 1397.3 X-LEAD=    698.7 T-MAX=     36.6 X-TMAX=      0.0
698.7 -628.8 -558.9 -419.2 -279.5 -139.7    0.0  139.7  279.5  419.2  558.9  628.8  698.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 7.67  13.16  18.07  26.16  31.94  35.41  36.56  35.41  31.94  26.16  18.07  13.16   7.6

95.0  PITCH= 5008.0  CHORD= 1401.1 X-LEAD=    700.6 T-MAX=     30.0 X-TMAX=      0.0
700.6 -630.5 -560.4 -420.3 -280.2 -140.1    0.0  140.1  280.2  420.3  560.4  630.5  700.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 6.43  10.91  14.91  21.51  26.23  29.06  30.00  29.06  26.23  21.51  14.91  10.91   6.4

97.5  PITCH= 5008.0  CHORD= 1400.5 X-LEAD=    700.2 T-MAX=     27.0 X-TMAX=      0.0
700.2 -630.2 -560.2 -420.1 -280.1 -140.0    0.0  140.0  280.1  420.1  560.2  630.2  700.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 5.83   9.85  13.44  19.36  23.59  26.13  26.98  26.13  23.59  19.36  13.44   9.85   5.8

00.0  PITCH= 5008.0  CHORD= 1400.5 X-LEAD=    700.2 T-MAX=     24.1 X-TMAX=      0.0
700.2 -630.2 -560.2 -420.1 -280.1 -140.0    0.0  140.0  280.1  420.1  560.2  630.2  700.
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.0
 5.26   8.84  12.05  17.33  21.11  23.37  24.13  23.37  21.11  17.33  12.05   8.84   5.2
```

# APPENDIX K

# DETAILS OF THE HULL GEOMETRY ANGLES



WATERLINE ANGLE FRAME ANGLE BUTTOCK ANGLE

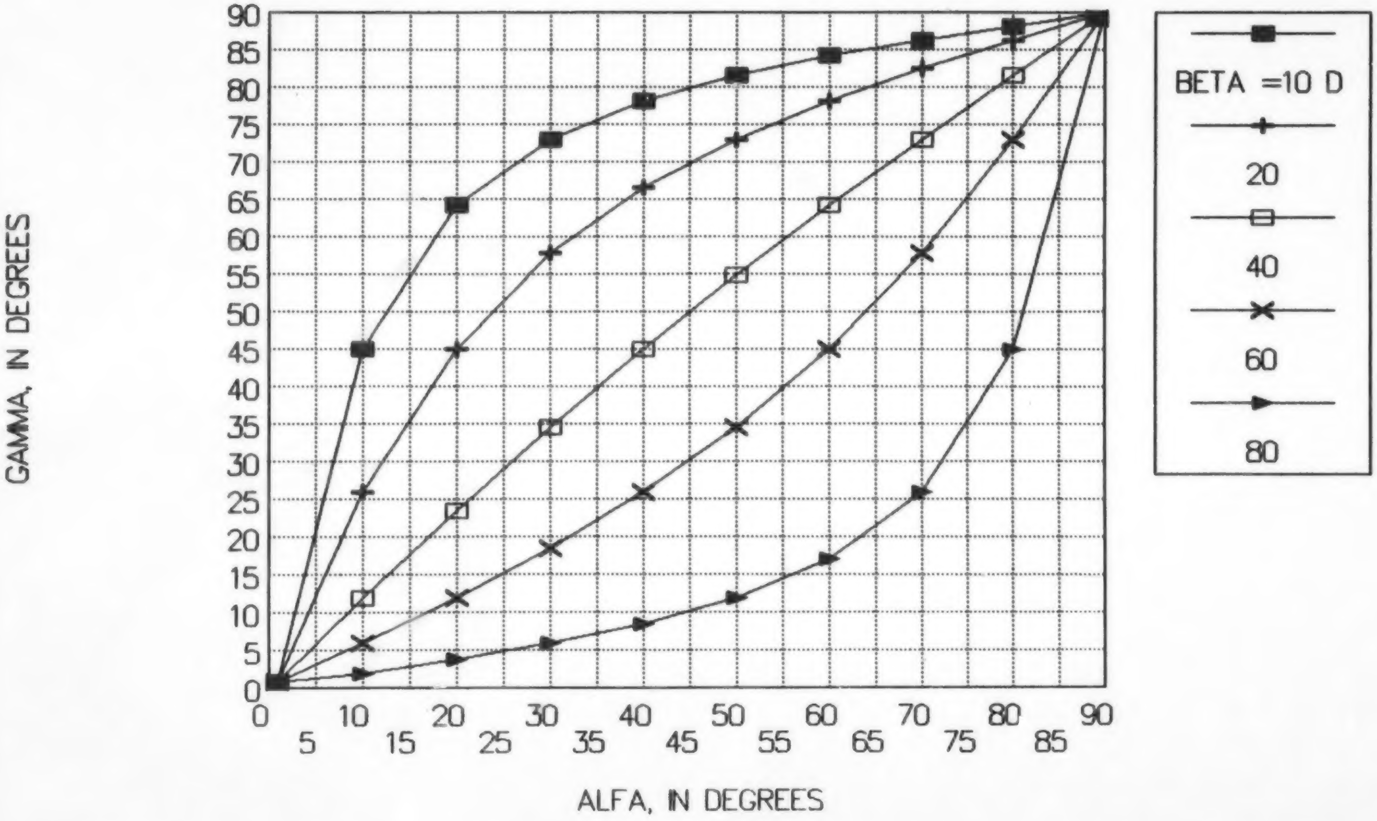


HULL PLANE ELEMENT VELOCITY DEFINITION

| | | | |
|---|---|---|---|
| FIGURE TITLE: HULL PLANE ELEMENT GEOMETRY DEFINITION | | | |
| PROJECT NAME: ICE FLOW AND BLOCKAGE | | | PROJECT NR: |
| DRAWN BY: VL | CHK'D BY: VL | SCALE: NONE | FIGURE NR: |

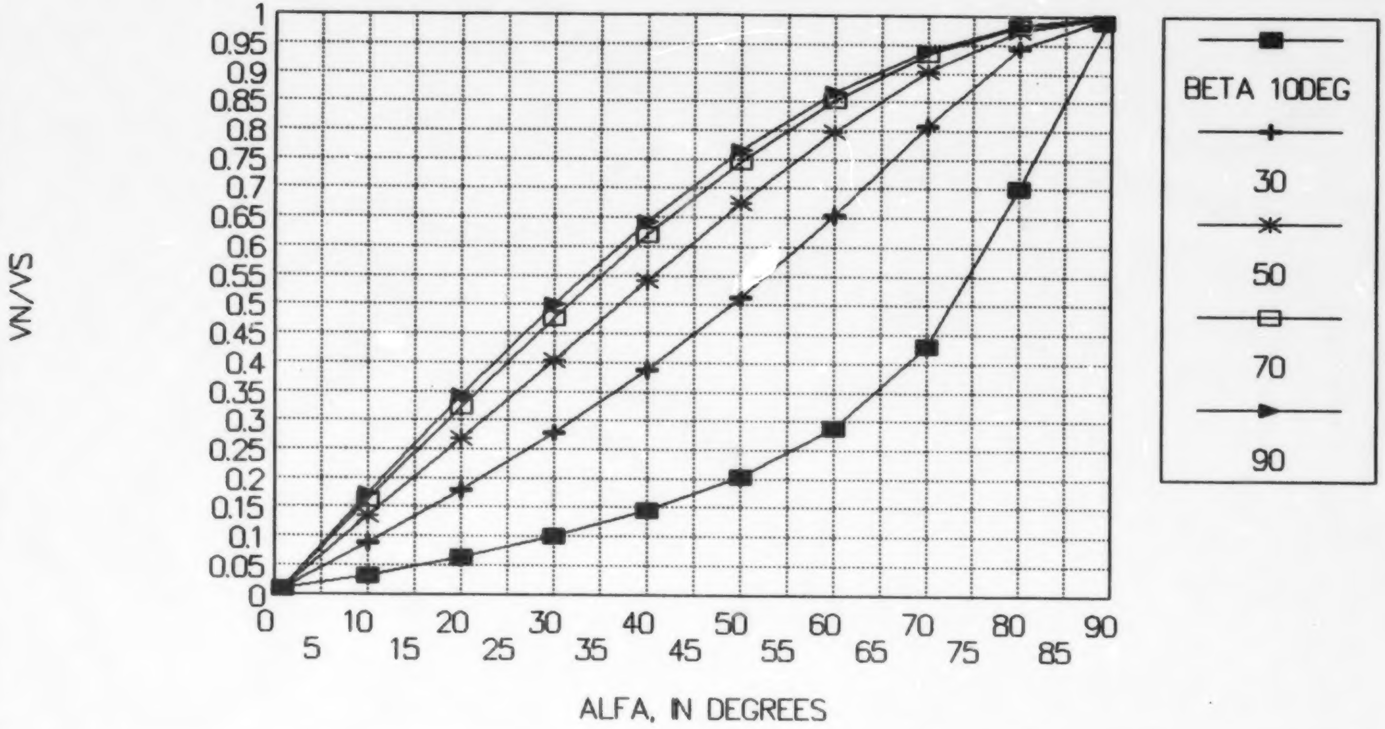
ARAD

# HULL ANGLES ALFA, BETA AND GAMMA

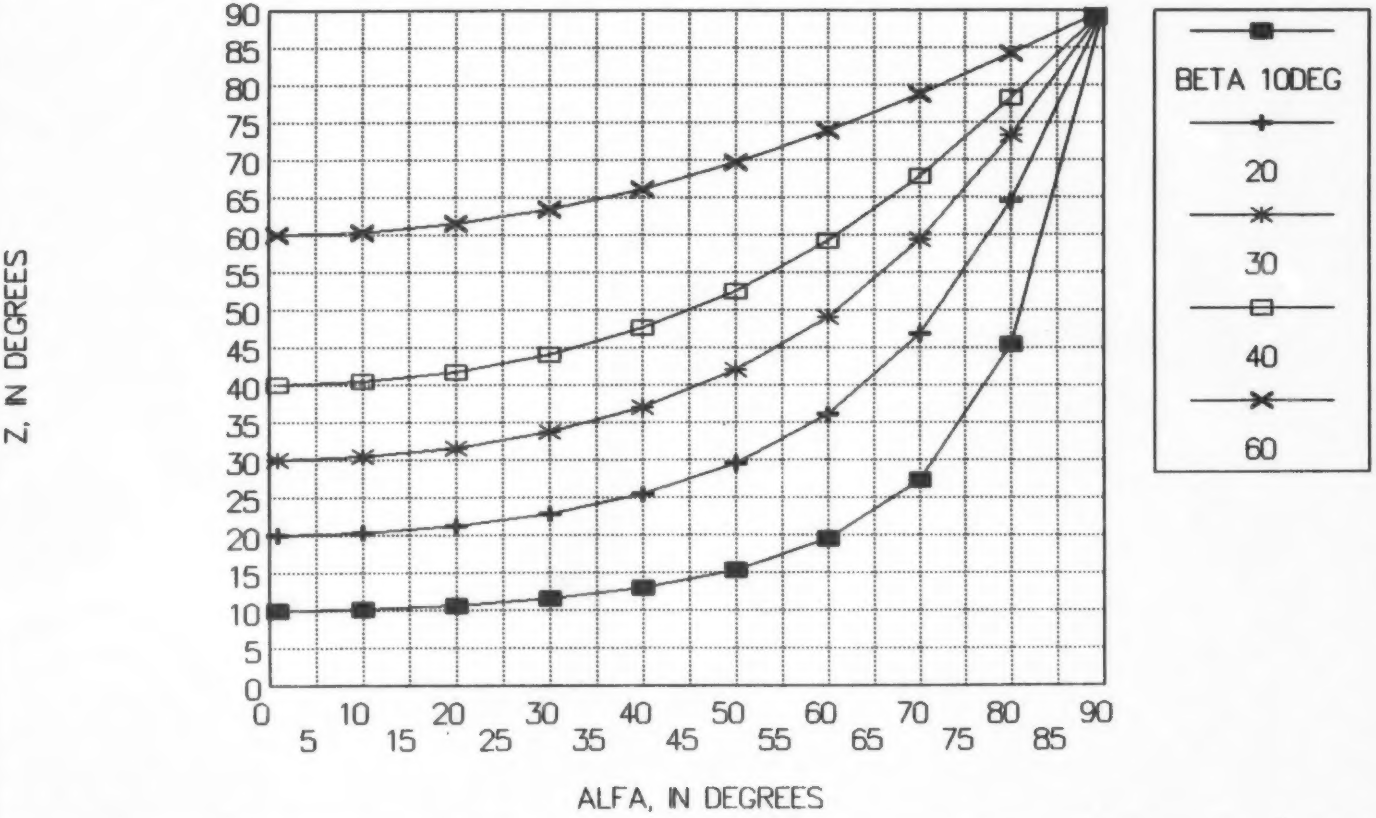


# NORMAL VELOCITY COMPONENT

## VN/VSHIP

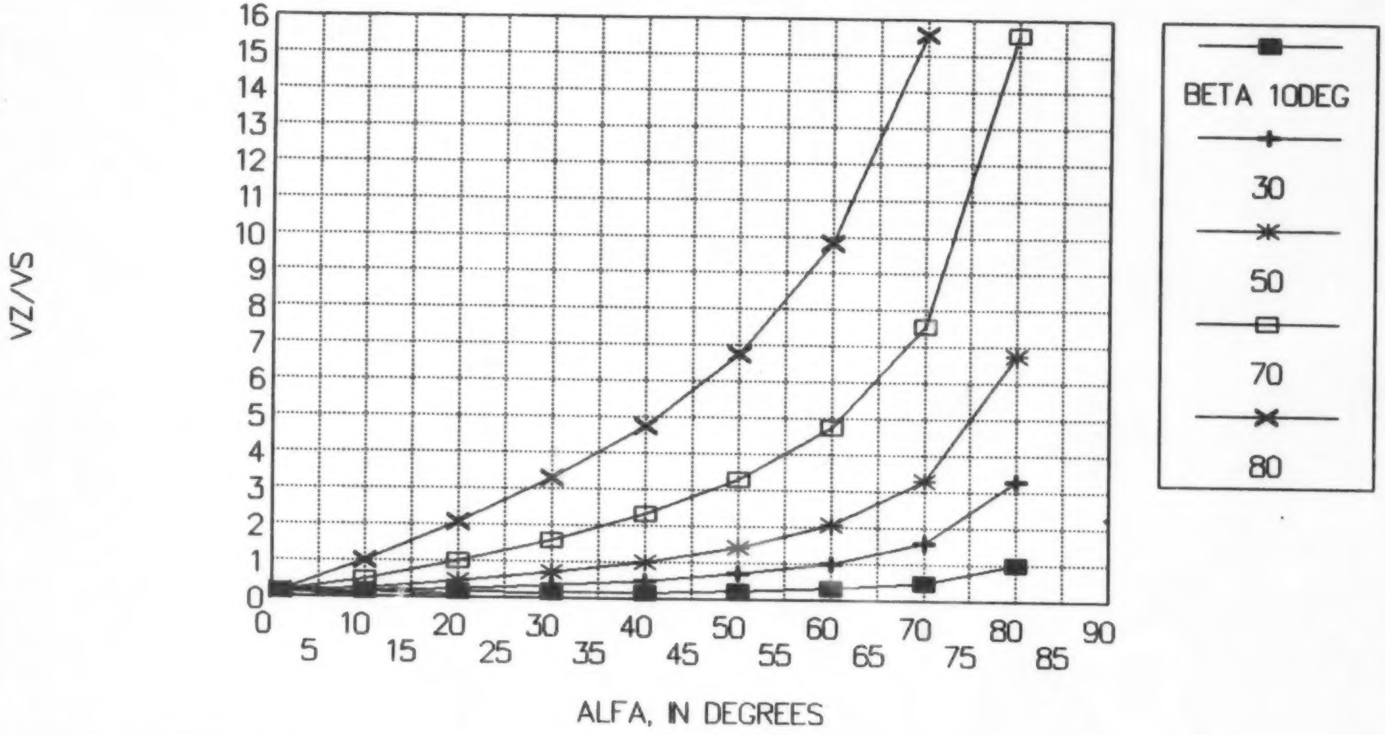


# HULL ANGLE Z (VERTICAL COSDIR)



# VERTICAL VELOCITY COMPONENT VZ/VS

## CONSTRAINED ICE



# VERTICAL VELOCITY COMPONENT VZ/VS
# UNCONSTRAINED ICE